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A STUDY ON FEASIBILITY AND METHOD OF IMPROVING FLOTATION FOR MOVING TYPES A2F, A4D, F4D, F4H, F8U-1 AND F8U-2 AIRCRAFT OVER UNPREPARED EXPEDITIONARY AIRFIELDS

November 2, 1962

Prepared Under Navy, Bureau of Weapons
Contract NOm72604
Final Report
PHASE I

E. G. GRAVENHORST
ARKWIN INDUSTRIES, INC.
WESTBURY, NEW YORK

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ARKWIN CONTROL EQUIPMENT

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FOREWORD

This Phase I report was prepared by Arkwin Industries, Inc., Westbury, New York under Navy Department Contract NOm72604. The Contracting Officer was Major R. H. Gemmell, USMC, Headquarters, U. S. Marine Corps, Navy Annex, Washington, D.C.

The author and engineer with general cognizance over this study was Mr. E. G. Gravenhorst, Vice President of Arkwin Industries, Inc. The study program was conducted under the direct supervision of Mr. J. A. Wiedmann, Chief Engineer. Mr. Thomas Lewis was Project Engineer; Mr. Lawrence Bruno was Design Engineer and Mr. Richard DeRois was Designer. Mr. E. H. Talbert of Milford, Delaware, Mr. Don Baus of York, Pennsylvania and Mr. W. Talbert of York, Pennsylvania contributed heavily to the program in the capacity of consultants.

Acknowledgement is also made for the cooperation and invaluable technical assistance provided by the following:

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ABSTRACT

The development of a method of moving aircraft over unprepared airfields involves study of various pertinent parameters and devices. This report consists of four basic sections. They are:

1. A study of possible soil and ground conditions. It is concluded that this condition is one defined by parameters of a forward-area airfield (as described by the U. S. Army Waterways Experiment Station).

2. A study of all possible methods of accomplishment, concluding that a system of three inter-connected dollies is most feasible and adaptable.

3. The development of a dolly system, evolving the most efficient and applicable means. This concept is shown on Plate 25, 26 and 48.

4. An analysis of steering methods and towing forces. It is concluded that forces involved can be acceptable values for worst possible ground conditions.

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BIBLIOGRAPHY

1. BEKKER, M. G. - "THRUST FOR PROPULSION"

2. BEKKER, M. G. - "FLOTATION AND MOTION RESISTANCE"

3. BEKKER, M. G. - "THEORY OF LAND LOCOMOTION"
"THE MECHANICS OF VEHICLE MOBILITY"

4. BOEHLER, G. - "AERODYNAMIC THEORY OF THE ANNULAR JET"

5. BOEHLER, G. - "BASIC PRINCIPLES OF GROUND CUSHION DEVICES"

6. JANOSI, Z.; BEKKER, M. G. - "ROLLING RESISTANCE OF PNEUMATIC TIRES IN SOFT SOILS"

7. LIBERATORE, E. K. - "A PARAMETER FOR COMPARING GROUND EFFECT MACHINES"

8. NORTH AMERICAN TREATY ORGANIZATION - "OPERATIONS FROM UNPREPARED AND SEMI-UNPREPARED AIRFIELDS"

9. TABOREK, J. J. - "MECHANICS OF VEHICLES"

10. TERZAGHI, K. - "THEORETICAL SOIL MECHANICS"

11. U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION - - "GROUND FLOTATION REQUIREMENTS FOR AIRCRAFT LANDING GEAR"

12. U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION - - "VALIDATION OF SOIL-STRENGTH CRITERIA"

I. INTRODUCTION

In the early days of flying, any area reasonably level and dry, with a strong turf for a running surface, was usually suitable for flight operations. As weight and speed of aircraft increased, more and more preparatory work became necessary for natural areas to become suitable.

One of the earliest attempts towards improvement was a variety of drainage systems. These were necessary to preserve the stability and bearing capacity of soils under changing weather conditions. Surface drains, sub-surface drains and land grading were all used depending on soil type, topography and availability of outlets.

Soil stabilizing processes were also applied. These included lime and fertilizer, better seedbed preparation and improved grasses to grow tough, dense turf. However, as wheel-loads and craft speeds continued to increase, limits of bearing capacities and wearing resistances of even the best grass runways were exceeded. Excepting those fields restricted to light planes, paving soon became standard procedure for runways and parking areas.

As airfield requirements became more stringent, engineering tests and studies kept pace. Publications placed considerable emphasis on paving and construction methods. Subsequent studies have been directed toward still further improvements in this technique.

However, in recent years, international tensions and conflicts have directed military research efforts toward objectives emphasizing mobility. Certainly permanent air stations with constructed runways have been located by surveillance systems. It must be taken for granted that these fields would be immediately destroyed. It would thus be mandatory that aircraft operate from unprepared areas.

At times it will be possible to improve these areas in some measure, and make them semi-prepared. But in most instances the lack of time and abundant materials will impose a condition whereby only a marginal portion of the area can be improved. Therefore, it must be expected that aircraft may be forced to operate from fields where only minimum areas are of substantial ground strength. These would be, specifically, the runway and perhaps the parking area.

The following are considered the prime objectives of this report:

1. Analyze the worst soil and terrain conditions upon which aircraft could be forced to operate.

2. Consider possible methods for ground transporting aircraft subject to the above conditions.

Evaluate these methods.

3. Demonstrate feasibility, advantages and disadvantages of the method considered or demonstrated most promising.

The types of aircraft considered for this report were the models designated as A2F, A4D, F4D, F4H, F8U-1, and F8U-2.

II. STUDY OF SOIL AND TERRAIN CONDITIONS

In considering the task of transporting various aircraft over a variety of unprepared areas, the initial question is one of soil and terrain. Certainly the success of an applicable device would be limited or enhanced under specific ground conditions. Criteria must be utilized to define accurately these conditions for specific areas.

The scope and intent of this project did not provide for soil, bearing load, and terrain experiments. Therefore, the intention is to evaluate recent studies, papers, and reports relative to aircraft operation from unprepared fields.

Several publications were selected as being proper reference materials. Among these were:

1. "Operations from Un-prepared and Semi-prepared Air Fields" - September, 1960 by the NATO Advisory Group for Aeronautical Research and Development.

2. The U. S. Army Engineer Waterways Experiment Station's Miscellaneous Paper No. 4-459, "Ground Flotation Requirements for Aircraft Landing Gear," December 1961.

3. The U. S. Army Engineer Waterways Experiment Station's Technical Report 3-554, "Validation of Soil-Strength Criteria," July 1960.

4. MIL - STD - 619A, "Military Standard Unified Soil

Classification System for Roads, Airfields, Embarkments and Foundations," March 1962. (Mandatory for use by Departments of the Army, Navy and Air Force.)

Charts and tables from the above have been included in this report.

These particular publications were selected for the following reasons:

1. The report by the NATO group because of its wider scope and because some of the conclusions therein might be interpreted as questioning, under certain conditions, recommendations in Misc. Paper No. 4-459.

2. Miscellaneous Paper No. 4-459 and Technical Report No. 3-554 because they were comparatively recent and contained extremely definite recommendations pertinent to the area of this present study.

3. The Unified Soil Classification System because it is now the mandatory standard for the Department of Defense.

The basis for Technical Report 3-554 is a series of actual soil strength tests conducted by the Air Force Operational Test Center. Tests were made under actual flight conditions in areas of unprepared, sandy soil with meager ground vegetation.

The tests were apparently quite successful and produced a number of findings from which conclusions were drawn and previous graphs were confirmed. Some of the more interesting findings were:

1. If tire pressure is held constant, an increase in wheel load does not increase depth of penetration.

2. An increase in tire pressure for a given load results in deeper ground penetration.

The basic conclusions reached were:

1. The minimum subgrade strength requirements are in agreement with those requirements indicated by previously developed California Bearing Ratio design curves (See plates 2 and 3).

2. Soil-strength criteria for operation of aircraft on unsurfaced areas (See plates 1 - 3),are as reliable as available data permits.

Because of the above references, copies of Plates 1, 2, and 3 are included with this report. Plate 1 shows the importance of keeping tire pressures to a minimum. Plate 2 provides criteria for this report: a single-wheel assembly, with 10 KIPS load and tire pressure of 35 psi, requires a CBR of 2.0 on unsurfaced soils for one coverage (about 40 landings). Similarly, Plate 3 determines that a multiple-wheel assembly, with 10 KIPS load per wheel and tire pressure of 35 psi, requires only a 2.4 CBR.

Miscellaneous Paper No. 4-459 provides data for selecting tires and tire pressures to support a given aircraft load without exceeding the ground strength of a given airfield. Six airfield categories are mentioned as applicable to this data.

One category is that to which this project applies. It is the forward-area airfield, an airfield constructed within limitations imposed by availability of methods, materials, and time. These fields would have a minimum of surface preparation, and in some cases none whatever.

A forward-area airfield is one which supports operation of light aircraft for a period of two to three weeks, with construction time of not more than three days. Medium and light cargo type aircraft with special flotation gear might also be required to use these airfields. This type of airfield is then classed as an emergency operational field having an unsurfaced or membrane-surfaced 4-CBR subgrade. Such an airfield will support approximately 10,000 lbs on a single tire inflated to a pressure of about 35 psi. Considering a 4 wheel dolly, the maximum loading for aircraft designated is calculated as approximately 6000 lbs per wheel.

Airfields constructed under the concept of the SATS program will be, in many respects, quite comparable to forward-area airfields with the exception that runways of limited size will be reinforced with suitable matting. On that basis, the above-mentioned curves are deemed to apply, within reasonable limits, to the unsurfaced areas of SATS airfields.

One method of determining soil bearing capacity is use of the California Bearing Ratio. This is actually a comparison of loads required to press a known area a given depth, first into a compacted sample of subject soil and secondly into a standard sample of known bearing strength.

Due to variable influences of moisture content, a test of soil bearing capacity only in regard to the California Bearing Ratio cannot give true indication of reaction to load. It becomes necessary to classify soil type with reference to the Unified Soil Classification System. Our classification then becomes one of both soil type and soil strength.

Different soil types vary widely in load reaction with changes in moisture. For example, with excess moisture, a soil composed of gravel and sand has high load capacity where a soil composed of clay or silt has low load capacity. Clay also is detrimental in that it contributes to low friction and adheres to tires, increasing efforts in ground handling procedures.

In addition to soil bearing strength, however, there are certain other factors which must be given consideration. The soil's condition, which may easily be affected by traffic, can be as decisive a factor as ground strength. For example, radical changes in moisture conditions can cause radical changes in bearing capacity.

Other factors in considering soil condition are the presence of snow and freezing. The effect of snow, of course, depends on many things, such as moisture, temperature, age, and depth. Actually the full effect of snow is completely unpredictable. Freezing is not detrimental if uniform. But if the ground surface thaws and the sub-surface remains frozen, water drainage is then impaired. The soil forms an unpredictable layer, making flight and ground handling extremely difficult.

In consideration of ground handling methods it should be pointed out that a vehicle is more likely to penetrate the ground when the vehicle is stationary, than during its period of motion. Certainly the vehicle should not be permitted to mire itself after removal from the runway. Therefore, parking areas should be reinforced, or at least properly selected.

Disregarding flotation, there is yet another extreme factor relative to function and feasibility. This is the effect of soil strength and condition upon towing forces. Since a towing device must be transported to remote areas of operation, it would be foolhardy to promote a flotation device which requires towing by a tractive device too massive for transport. Thus towing effort alone could render worthless any means of flotation. There are several factors influencing the magnitude of towing forces. Among these are:

1. Total weight of aircraft plus flotation device.

2. Total ground area supporting this weight.

3. Cohesive strength of the soil and its related bearing strength.

4. Condition of the soil, whether adhesive, cohesive, slippery, abrasive, compacted or loose.

5. Amount of rigidity or flexure of rolling members of flotation devices. For example the flexure of a tire is reduced considerably when cooled, its contact area reduced, and ground penetration thus increased.

6. Slope and topography of field terrain.

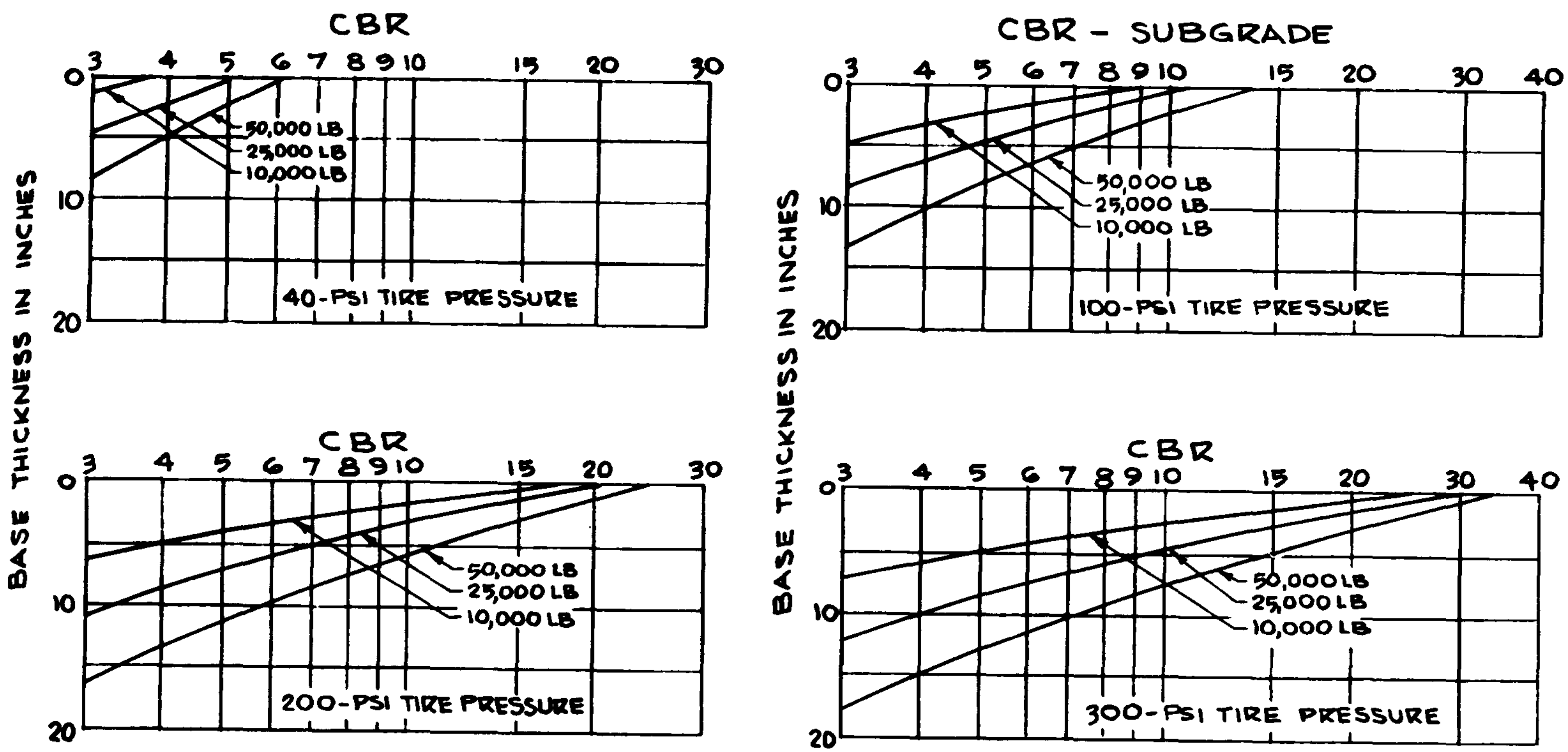
All of these factors are directly related to penetration of ground surface and rolling friction. Slope and topography, of course, determine components of weight. However, this effect, in most cases, would be considered negligible.

It is certainly possible, that for a given weight and a given field, flotation areas can be selected whereby towing forces will exceed weight of the aircraft. Therefore, consideration is given not only to proper weight support, but also to means offering minimum towing forces. In later portions of this report (namely the section discussing various means of flotation and the section on procedure of development) this aspect is considered in detail.

Under the SATS program, it may not always be possible to select a well-drained area adjacent to the matted runways. There may neither be time nor facilities to install proper drainage systems. A dense turf would increase bearing capacity and reduce slipperiness. But none may exist, or if so, it may be destroyed by grading and clearing operations. As a final handicap, SATS must be prepared to go anywhere in the world, including tropical areas where rainfall is often intensive.

Considering these problems, and with consideration of the references used, it must be concluded that the recommendations in Miscellaneous Paper No. 4-459 should constitute absolute minimum requirements for flotation of aircraft over unprepared surfaces. Further, within limits of practicability, cost and function, the use of low bearing values would be in the best interests of the SATS program. Also, in line with the findings of Tech. Report 3-554, every effort should be made to use lowest possible tire pressures, if tire augmentation or auxiliary wheels are used, to provide plane flotation. As the ideal condition, flotation should be provided for the worst condition possibly encountered. This condition would be encompassed by a field with a ground bearing strength only suitable to support walking personnel or tractive equipment. The ground pressure in either case would be less than 15 lbs per square inch. This is the ultimate goal of this program

FROM W.E.S. U.S. ARMY ENGR. TECH REPORT 3-554



FOR SINGLE WHEELS

40 COVERAGES

PLATE 1

THEATER OF OPERATIONS CBR DESIGN CURVES FOR UNSURFACED AND MEMBRANE SURFACE SUBGRADES. SOIL STRENGTH DECREASES WITH DEPTH.

EMERGENCY OPERATIONAL CATEGORY

FROM W.E.S. U.S.ARMY ENGR. TECH REPORT 3-554

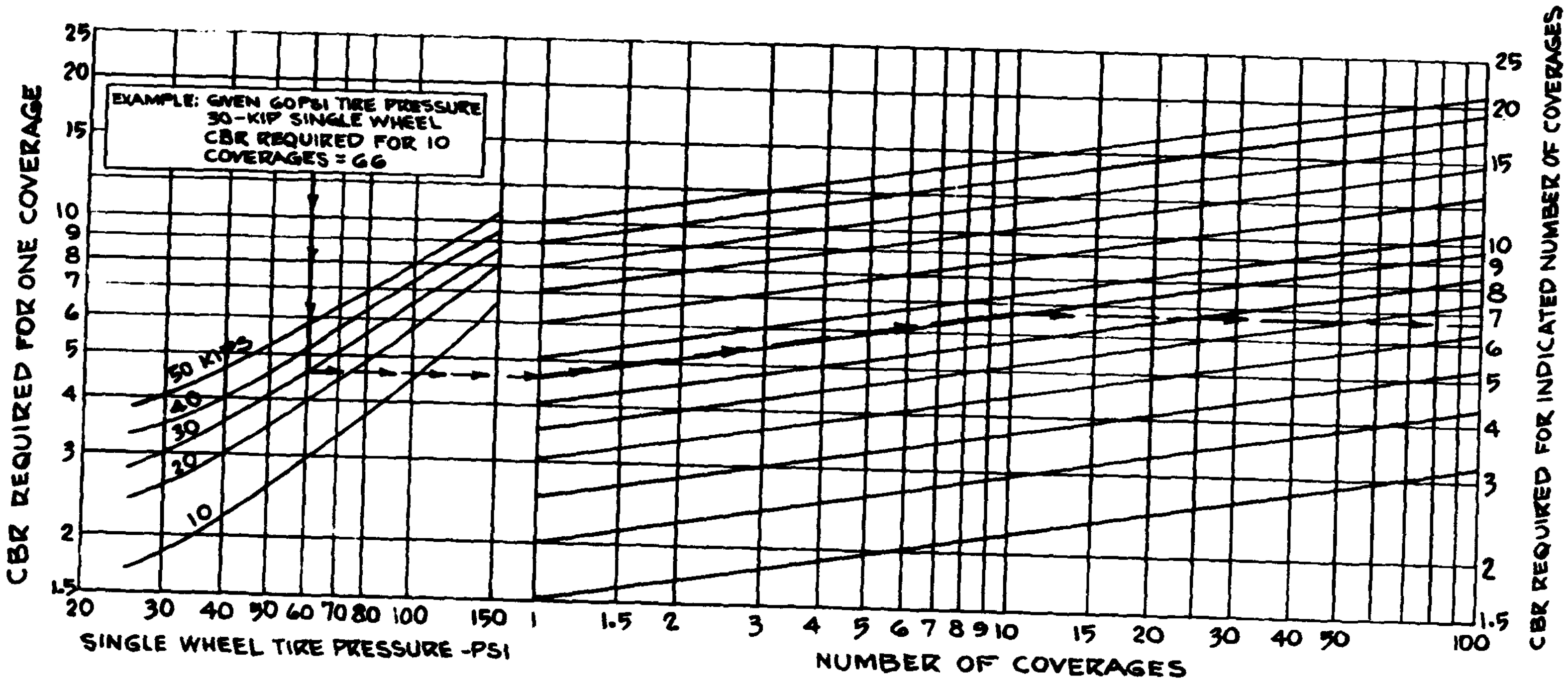


PLATE 2.

CBR REQUIRED FOR
OPERATION OF AIRCRAFT
WITH SINGLE-WHEEL ASSEMBLIES
ON UNSURFACED SOILS
STRENGTH CONSTANT OR INCREASES
WITH DEPTH

FROM W.E.S. U.S. ARMY ENGR. TECH REPORT 3-554

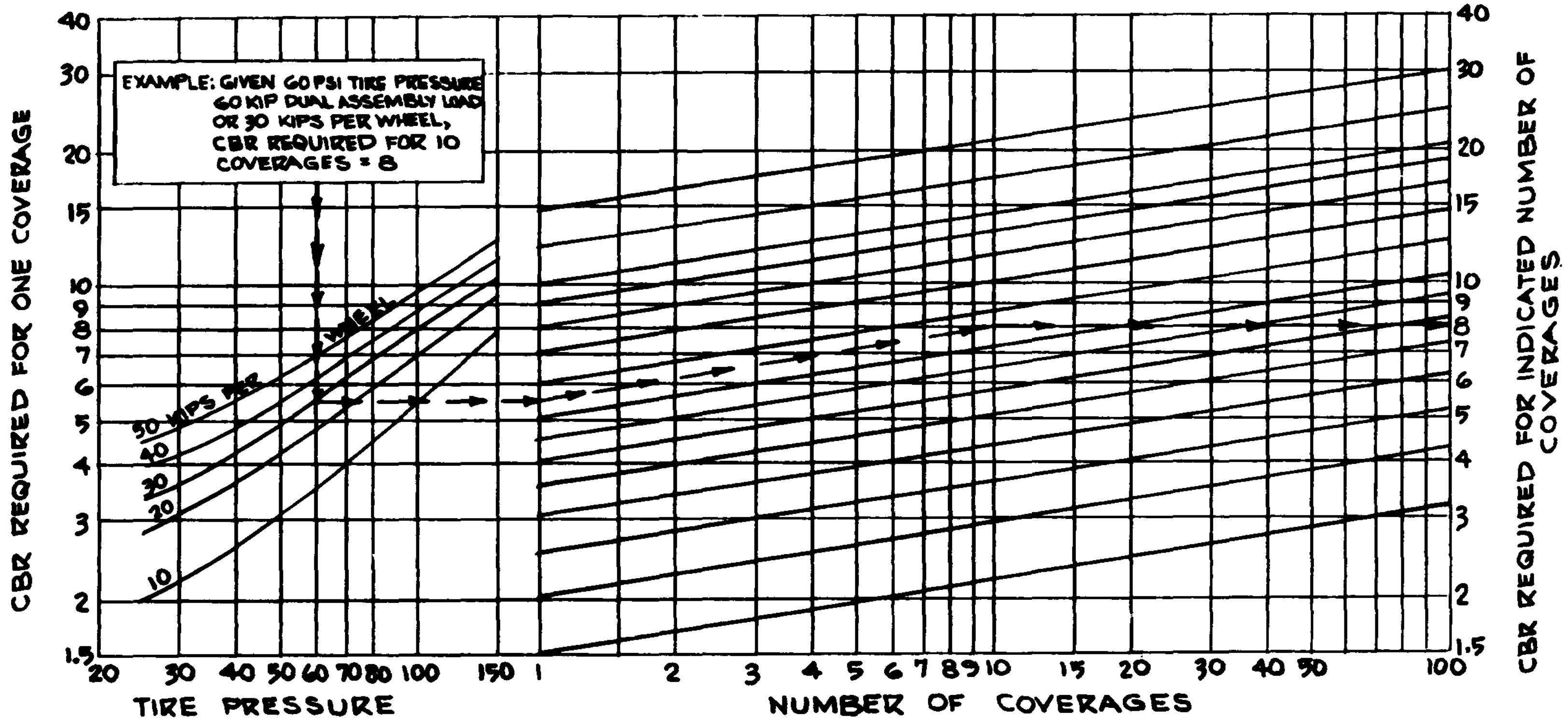
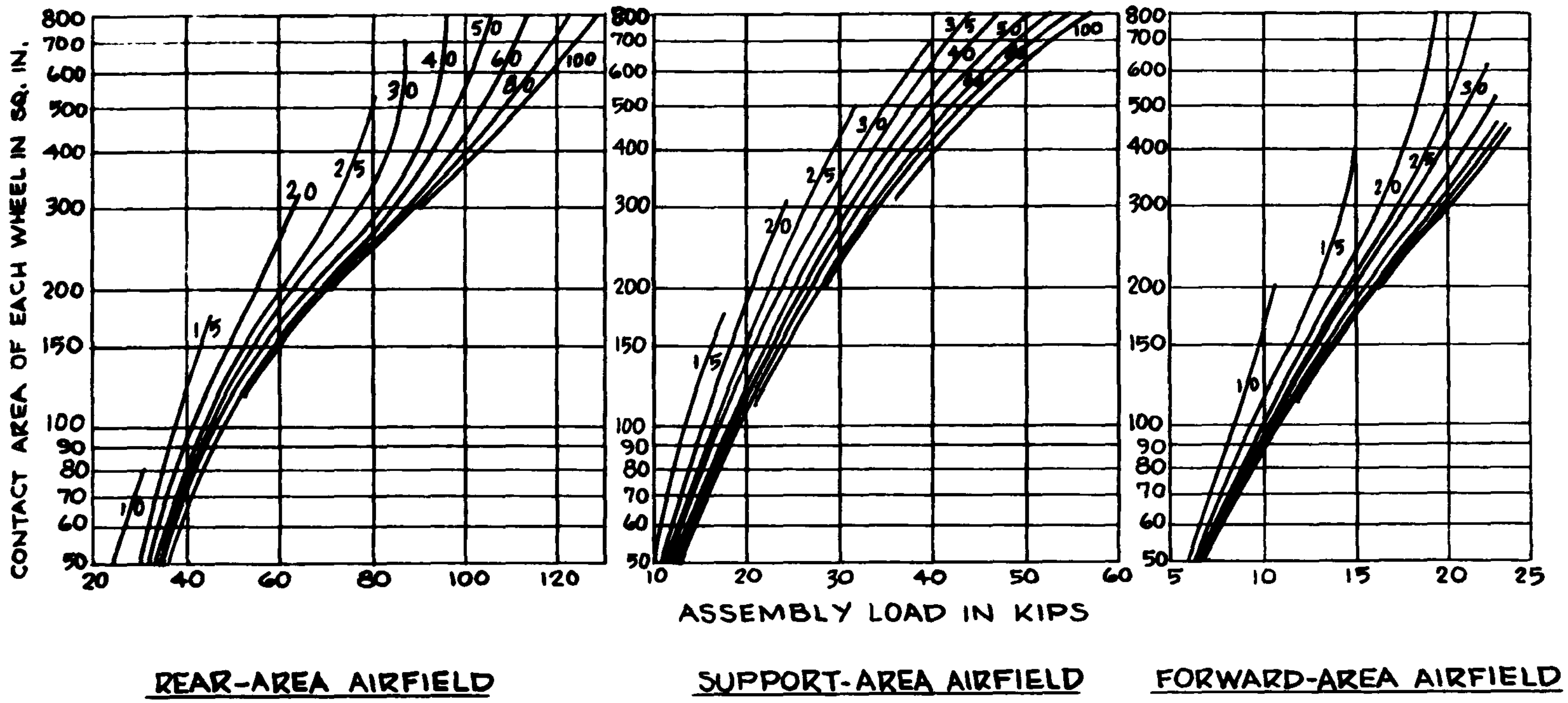


PLATE 3
CBR REQUIRED FOR
OPERATION OF AIRCRAFT
WITH MULTIPLE-WHEEL ASSEMBLIES
ON UNSURFACED SOILS
STRENGTH CONSTANT OR INCREASES
WITH DEPTH

FROM W.E.S. U.S. ARMY ENG. MISC. PAPER NO. 4-459



NOTE: NUMBERS ON CURVES DENOTE C-C SPACING OF TWIN WHEELS IN INCHES.

PLATE 4.
GROUND FLOTATION REQUIREMENTS

TWIN ASSEMBLY OR SINGLE TANDEM ASSEMBLY
REAR-, SUPPORT-, AND FORWARD-AREA AIRFIELDS

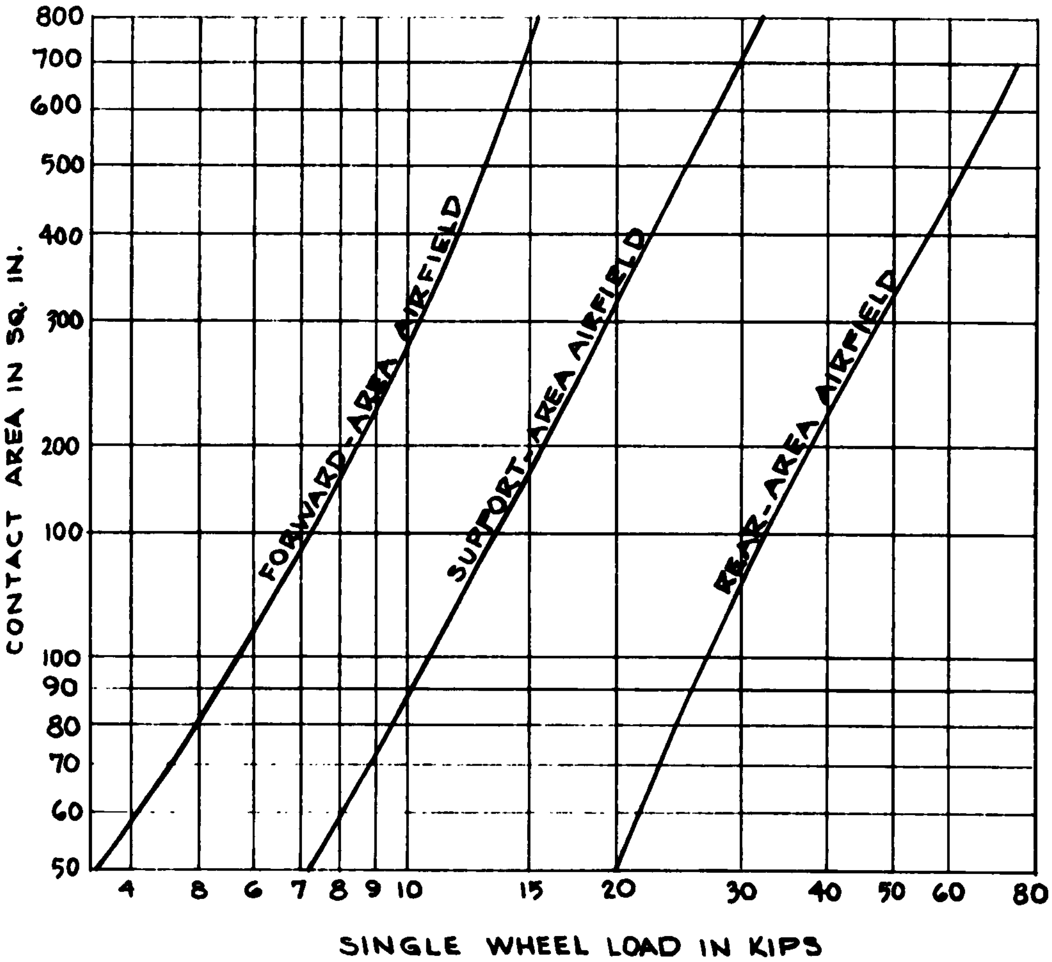


PLATE 5.
GROUND FLOTATION REQUIREMENTS
SINGLE WHEEL
FORWARD-, SUPPORT-, AND REAR-AREA AIRFIELDS

FROM W.E.S. U.S. ARMY ENG. MISC. PAPER NO. 4-459

III. DISCUSSION OF OTHER FLOTATION METHODS

There are many approaches to the solution of aircraft flotation over unprepared areas. The following is a listing of major concepts proposed in the past:

1. Soil Stabilization.
2. Tire Augmentation.
3. Trailers.
4. Skids.
5. Caterpillar Tracks.
6. Wheel Dollies.
7. Other Approaches.

Each of the above concepts will be discussed with respect to its applicability to the SATS program.

Soil Stabilization

Considerable work has been done by various public and private agencies in the development of soil stabilization methods to permit movement of vehicles over areas which in their natural state would not support the required loads. To be completely effective without auxiliary flotation, such stablization methods would have to increase soil load bearing capabilities to a point of sustaining pressures in excess of several hundred pounds per square inch. This is far in excess of the capabilities of any present day stabilization technique that could be considered feasible; feasible from a standpoint of amount of stabilizer material required as well as the amount of processing equipment required. The quantity of stabilizing material required depends of course on type and condition of the soil. Under certain conditions, as much as ten tons of stabilizing material is required per 10,000 square feet of surface area to effect any significant increase in load capacity.

The problem of transporting the vast quantities of material necessary to effectively improve even the minimum of storage and maintenance areas would be tremendous. In addition, transport of the equipment necessary to process the soil would entail the use of even more valuable transport capacity.

A survey of those reports covering stabilization techniques, investigations and evaluations indicate that the present techniques do not effectively lend themselves to off-runway or landing area use. Under certain conditions soil stabilization thru mechanical operations or stabilizing additives may be feasible as supplements to other flotation means.

Tire Augmentation

Any method increasing load bearing area to reduce bearing pressure improves mobility of the aircraft over unprepared soils. The attachment of additional wheels or tracks to the existing aircraft tire or wheel will have the effect of substantially decreasing ground pressure. In all cases, on aircraft included in this study, the main landing gear wheel axles are cantilevered from the main shock strut. Any load carrying additions to the wheels would by necessity be on the side opposite the half-fork strut. They could never be attached in such a way as to provide a symetrical loading to the axle. Addition of a sufficient number of wheels to decrease the bearing pressure to an acceptable level would necessitate addition of several feet to the effective length of the wheel axle. This greatly increases both the vertical bending moments and the torque resisted by landing gear members.

An example of track augmentation added directly to the wheels is shown in the E. L. France patent (Plate 6). To be effective at all, devices of this type must be loaded symetrically about the center line of the wheel.

Stores interference on the A4D and F4D aircraft would prevent the installation of even a minimum of augmentation devices.

Trailers

Trailers, consisting of a large platform mounted on wheels, are often used to transport heavy loads. If properly designed, the frame will prevent any of the towing forces being transferred to the aircraft. If weight and size are disregarded there is almost no limit to load bearing area that can be designed into trailer wheels. In the case of support equipment for the SATS program, size and weight are of prime interest; design must be efficient in the use of material.

For the most efficient design, trailer wheels should be placed directly below the aircraft wheels, keeping number and size of the trailer load carrying members to a minimum. Compromises must be made to permit transportation of the various aircraft under consideration because of large variations in wheel location. The main gear treads vary from 214 inches for the F4H to 93 inches for the A4D. Likewise the separation between the nose wheel and the main gear center line varies from 286 inches for the F4H to 140 inches for the A4D.

Several different approaches to the design of trailers have been investigated. Two of these approaches are covered by the Paul Patent (2,798,729) and the Lehman Patent (561,744-Italy).

A sketch of the Lehman concept is shown in Plate 7 of this report. Without question, this idea affords good flotation, permits travel over rough terrain and does not transmit towing loads into the aircraft. However, this design cannot permit wide choice of tire sizes and types to provide adequate load bearing area.

There are several obvious faults which make it unsatisfactory for use in the SATS program. It is relatively heavy because the nature and location of the loadings make it necessary to use relatively large structural members. The size and configuration of many of the elements will make shipping and standby storage a considerable problem. In its present form it is not adjustable and could not accommodate many types of planes. This might be corrected but not easily. Also, the plane must be transported in a very high position.

This not only develops instability but presents the problem of accomplishing this amount of elevation. Forward movement of the plane in the process of loading is also greater than desirable. The final problem is that it might prove difficult to maneuver the plane during loading so as to achieve positioning of the main wheels with respect to the ascending ramps.

The Paul System (shown on Plate 8) overcomes several of the above objections, but unfortunately has certain other faults. The Paul aircraft transporter would be even heavier than the above. It would conceivably be even more difficult to ship and to store. It does not provide as much flotation as the Lehman carrier, although this might be improved by a better tire arrangement. Forward movement of the plane during loading is just as great as required by the Lehman System and the problem of centering the main landing gear wheels on their carriers has not been solved.

However, the Paul unit is adjustable and could be made to fit all planes under consideration. How readily these adjustments could be made under field conditions, however, would require extremely serious consideration. Airplanes can be carried at any desired elevation, which is a good feature, and in addition, this transporter has other advantages, similar to those of the Lehman idea, because of basic trailer design.

The basic disadvantage of having long load carrying members, inherent in this design, is true of all trailer concepts. For this reason any approach using the trailer concept can not be of optimum weight.

Skids

Skids of various types have been used in place of wheels on aircraft for many years. Skids or skis are regularly used on light aircraft for take-off and landing on snow. Special skis, with the lower surfaces coated with Teflon to provide a low friction surface to which snow will not adhere are in regular use on aircraft as large as the C130 for certain support operations in the Antartic. The greatest success with skids are on snow because of its inherently low coefficient of friction.

Skids were used before the wheel was invented and are still used where the loads are relatively light and the frictional drag is not a problem. To drag a loaded airplane of the size of the F4H from the metal landing mat on skids would require a tractor capable of providing a drawbar pull in excess of 35,000 pounds. Until suitable low friction coatings and materials are developed, capable of withstanding severe wear problems associated with traversing rough and rocky ground, skids must be considered unsatisfactory for aircraft flotation.

Caterpillar Tracks

Tracks of various types are used to provide flotation for heavy equipment and are familiar to everybody on the well known "Cat" Tractor, tanks, and many off-the-road vehicles. The complicated mechanism associated with high speed tracks has resulted in considerable research directed towards other method of providing large ground contact areas.

Specially designed track gear have been tested on large aircraft such as the B36 and the C119 without notable success. Although the idea was basically sound and offered certain advantages, some of the problems were never fully solved. Weight and size are of extreme importance in the design of airborne equipment and many compromises had to be made to make design compatible with the space and weight limitations of the aircraft. The very high speeds associated with aircraft take-offs and landings also imposed severe stresses and environments that exceeded the capabilities of the designs.

The failure of tracks under these severe conditions should not prevent further study of their use on the "SATS" program. Tracks offer rather fantastic bearing areas and can be designed to use available space around the landing gear. The stresses associated with the low towing speeds of off-runway operation would only be a fraction of the stresses during landing or take-off. The problem of thrown belts, etc. is no longer a threat.

Because of low ground bearing pressures associated with designs of this type, recommendations covering design of a track type unit are presented later in this report.

<u>Wheel Dollies</u>

The use of a wheeled dolly to support each wheel of the aircraft is the concept originally presented. Dollies have certain advantages which make them of interest in this program. Being placed directly under each wheel the size and weight of load carrying members are held to an absolute minimum. This offers considerable weight saving over that associated with a trailer concept. This weight saving is a significant factor, both in transportation of the unit and in handling when positioned under the aircraft.

The dolly is more readily adapted to flotation than other approaches, such as tire augmentation, because the dolly wheels can be positioned to clear external aircraft stores without inducing large unsymetrical loads in the landing gear.

The use of wheels rather than skids permits considerable reduction in the required drawbar capacity of towing equipment.

The addition of tie-rods to position the three dollies with respect to each other provides an effective way to eliminate any unusual loads resulting from improper dolly tracking. This results in a configuration possessing load distributing advantages of a trailer without the weight penalty. Various configurations of dollies have been considered for use in this program. A typical unit is the Page Patent shown on Plate 9. Although as shown it is designed for support of the main gear only, a third dolly could easily be added. In the case of the Page unit the aircraft must be rolled onto the support platform, requiring rather critical control of aircraft movement while being positioned on the dolly.

The concept of using inter-connected dollies, each dolly capable of lifting the aircraft and properly positioning itself, is the concept covered in detail for this study.

Other Approaches

There are several other basic approaches to the solution of flotation augmentation and, although they do not adapt very well to the SATS program, they should at least be discussed for completeness.

High capacity cranes mounted on large vehicles are capable of lifting entire aircraft for transportation. Large low pressure tires permit movement of the vehicle over comparatively soft ground. Such equipment is presently used to retrieve crashed planes for transportation back to the base. The physical dimensions of such a retriever are quite large, it is heavy and does not lend itself to transportation by air.

A low pressure air flotation system operating as a ground effect machine has been studied by at least one major airframe company as a solution to mobility over unprepared fields. Considerable work has been done on GEM's during the past few years and many applications are being developed for their use. The operating height of a GEM used to transport the aircraft concerned in this study could be of the order of 0.5 feet for terrain clearance. As a circular configuration is most efficient from a power standpoint our analysis will be based on such a design. Taking a conservative disk landing of 30 pounds per square foot, the diameter of a GEM capable of supporting the F4H aircraft would be in the order of 80 feet. The horsepower required to supply the air will, of course, depend upon the type of annular jet and peripheral seal used, but a rough estimate of the power requirements indicate it would be well in excess of 1000 BHP.

Again, the problem of transporting such large and heavy equipment prevents its consideration in this program.

WRAPPING WEB TREAD FOR AUTOMOTIVE VEHICLE

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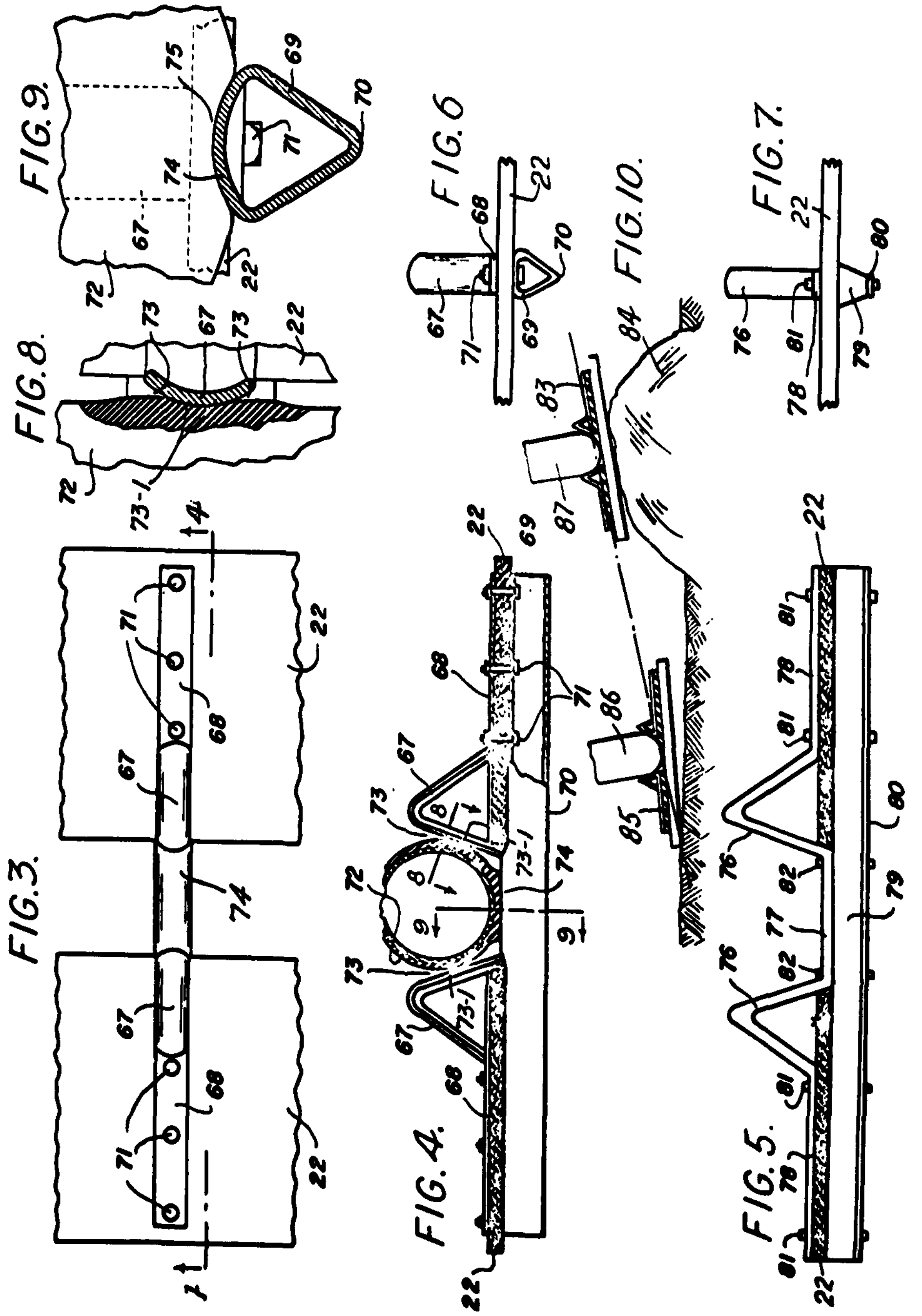

PLATE 6.

ARKWIN CONTROL EQUIPMENT

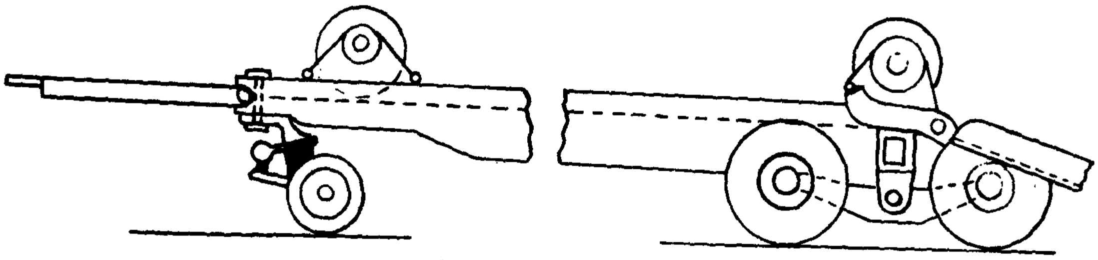

FIG. 1

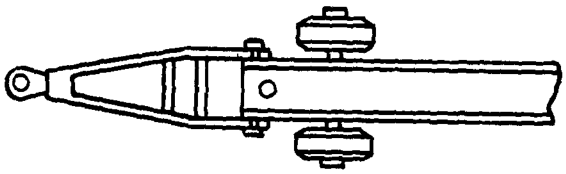
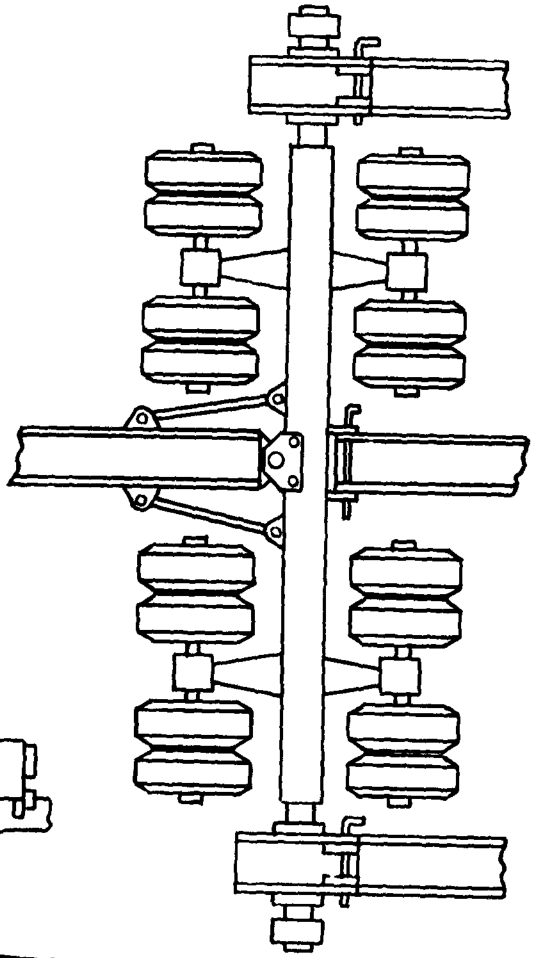

FIG. 2

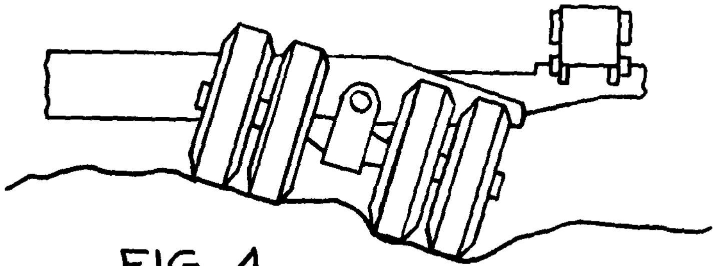

FIG. 4

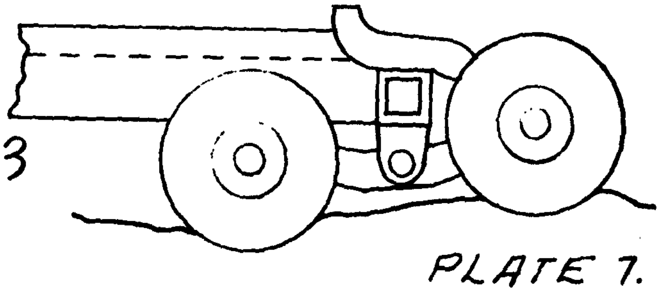

FIG. 3

PLATE 7.

July 9, 1957 A. PAUL 2,798,729

CARRIER FOR THE TRANSPORT OF AIRCRAFT ON THE GROUND

Filed March 30, 1956 3 Sheets-Sheet 1

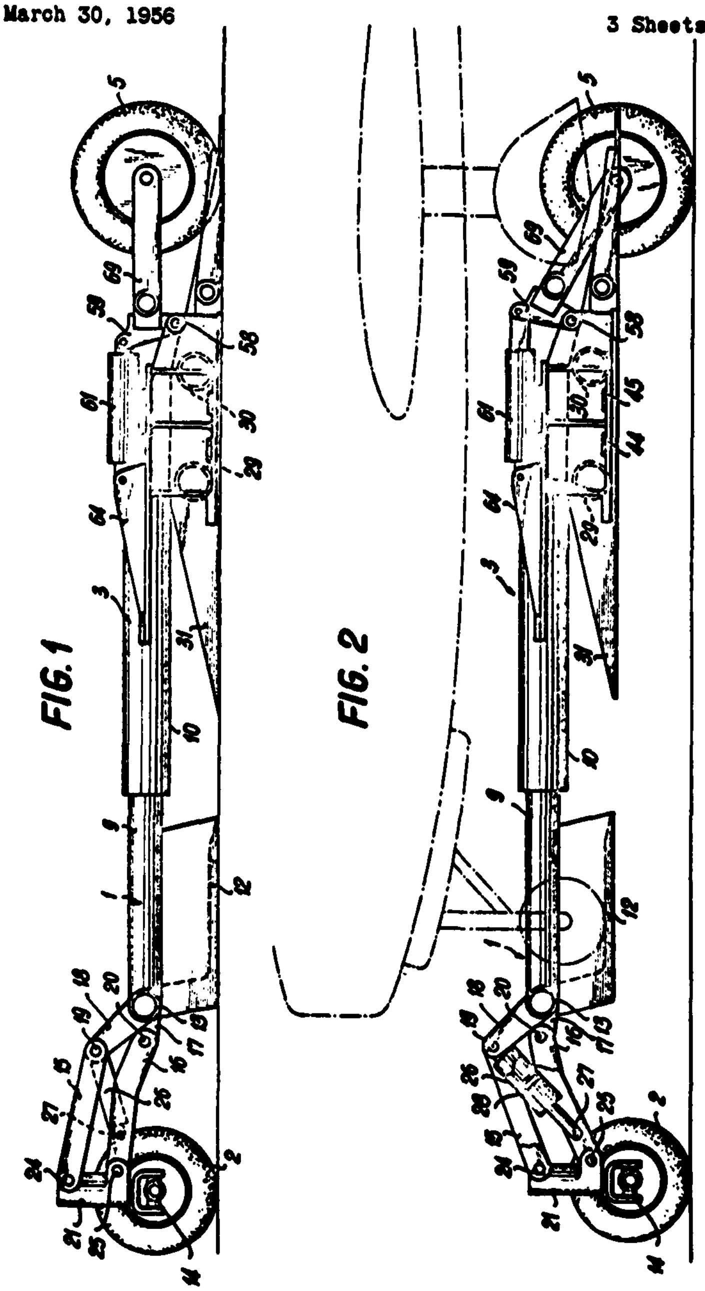

FIG. 1

FIG. 2

PLATE 8

CARRIER FOR THE TRANSPORT OF AIRCRAFT ON THE GROUND

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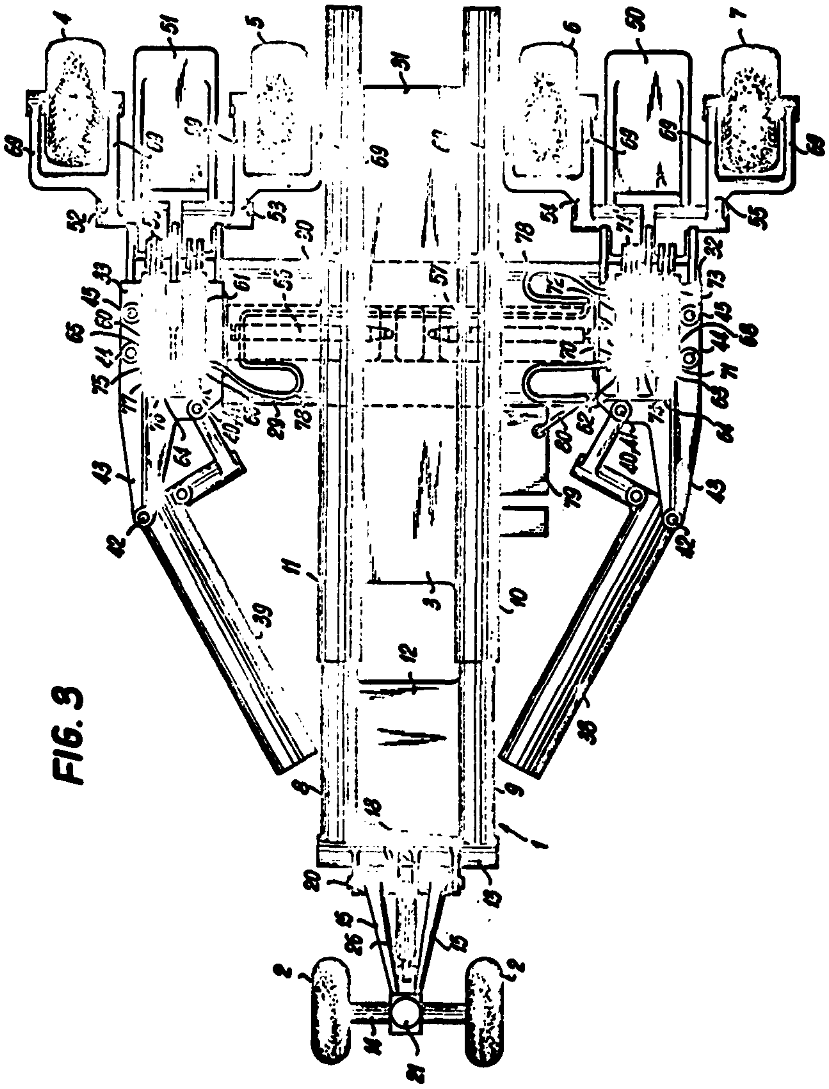


FIG. 3

PLATE 8

July 9, 1957 A. PAUL 2,798,729

CARRIER FOR THE TRANSPORT OF AIRCRAFT ON THE GROUND

Filed March 30, 1956 3 Sheets-Sheet 3

FIG. 4

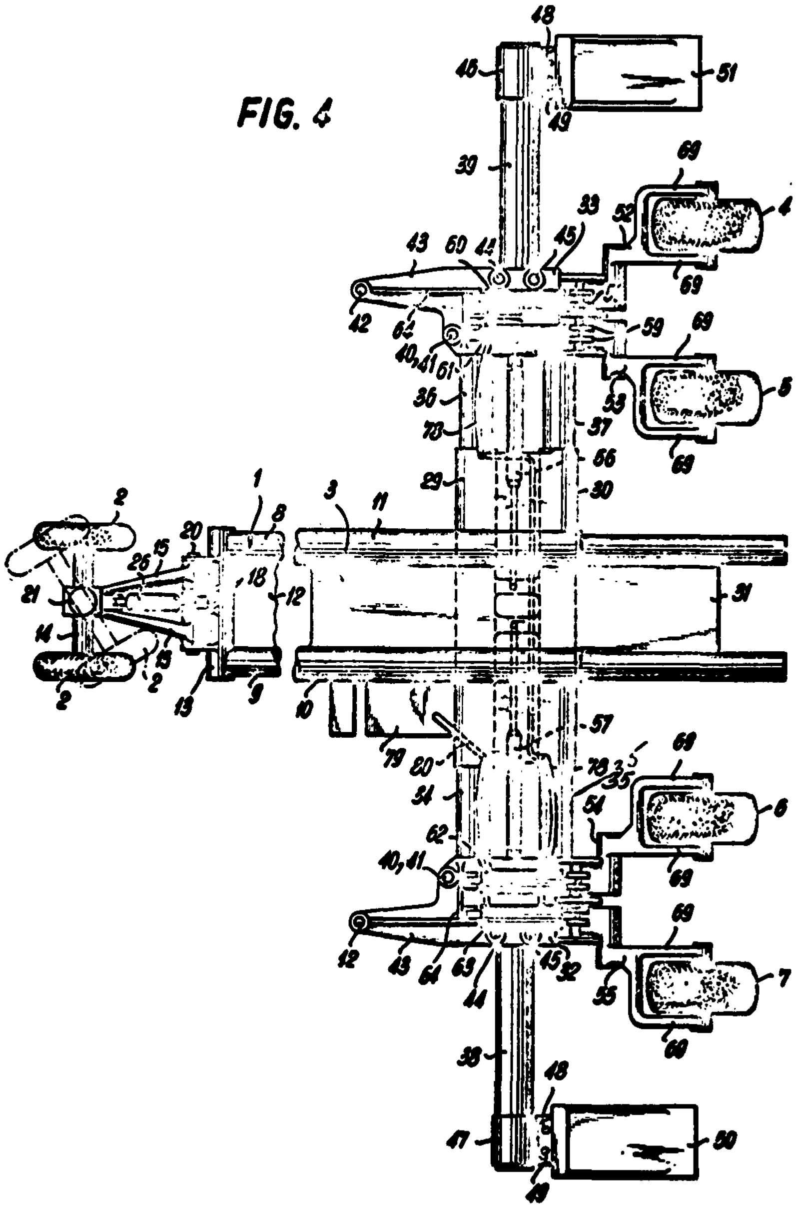


PLATE 8

Dec. 25, 1945. E. PAGE 2,391,503

APPARATUS FOR FACILITATING THE TRANSPORT OF AIRCRAFT

Filed March 10, 1943 2 Sheets–Sheet 1

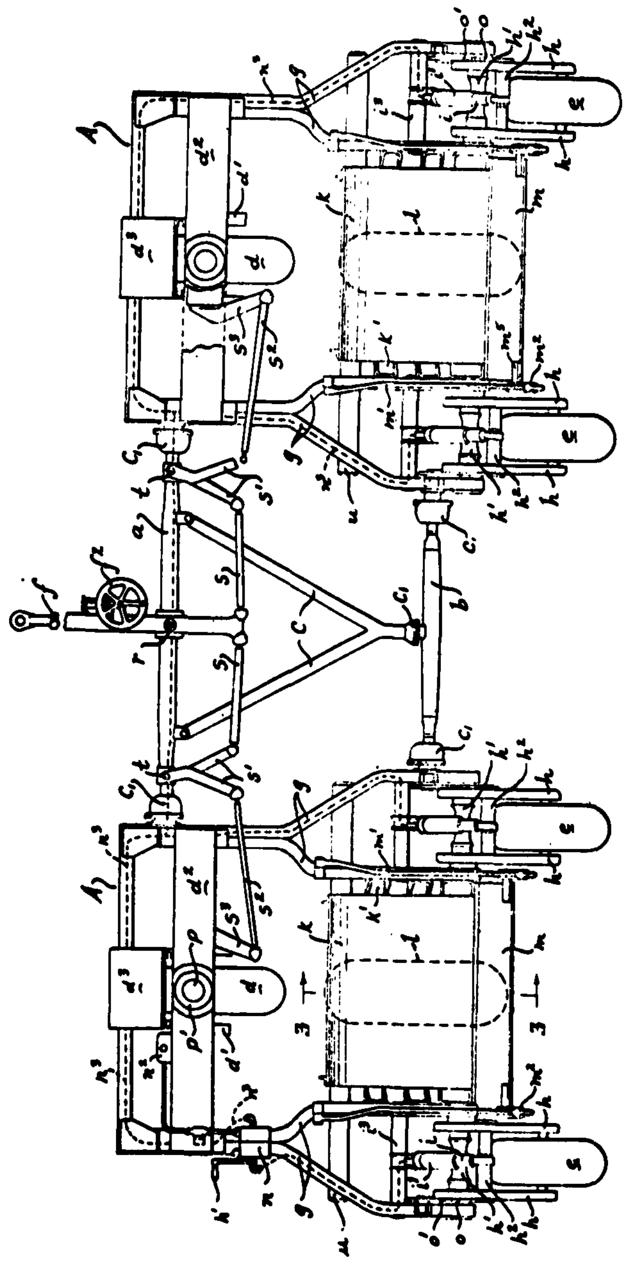


Fig. 1

PLATE 9

Dec. 25, 1945. E. PAGE 2,391,503

APPARATUS FOR FACILITATING THE TRANSPORT OF AIRCRAFT

Filed March 10, 1943 2 Sheets-Sheet 2

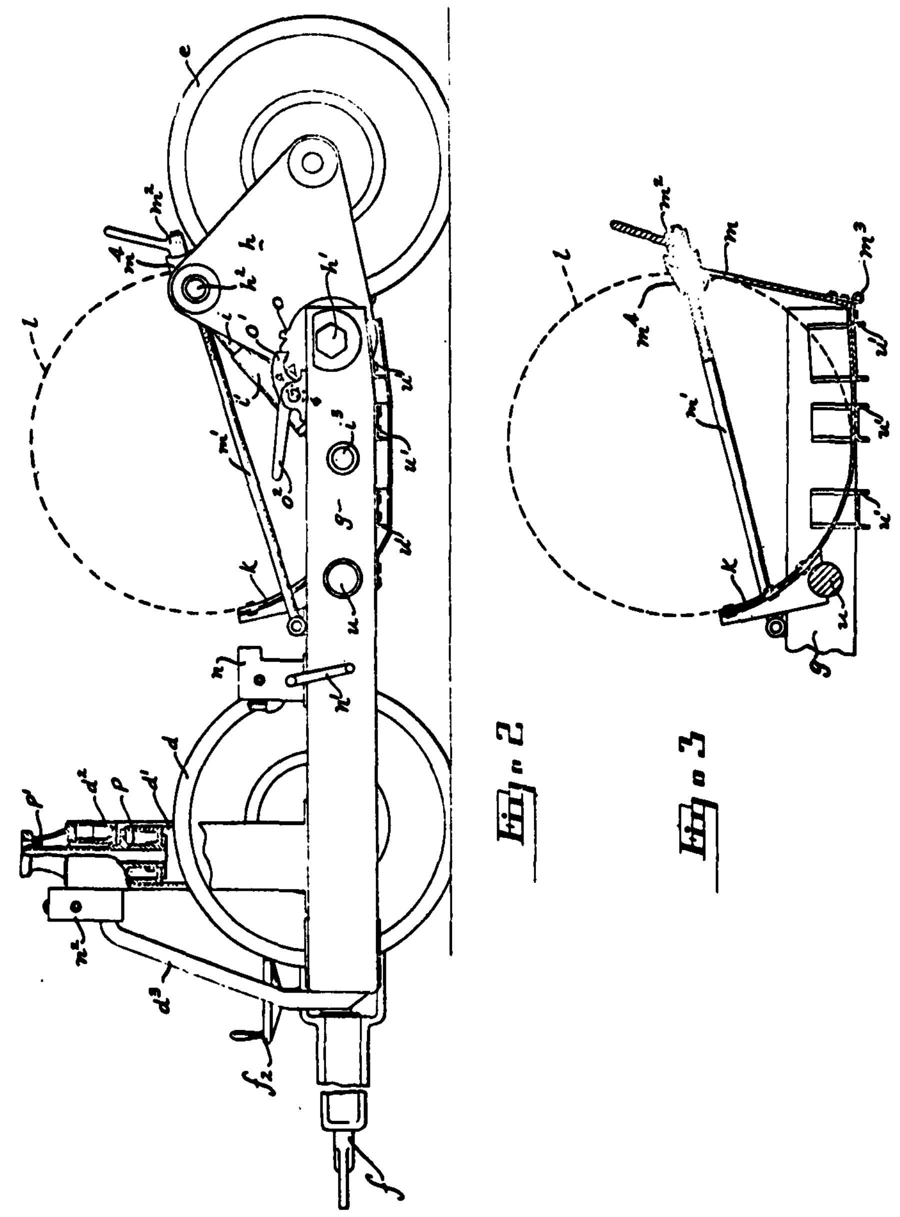


Fig. 2

Fig. 3

PLATE 9

IV. PROCEDURE OF DEVELOPMENT

1. Preliminary Study

Initially, the flotation concept previously advanced by Arkwin Industries was studied (See Plate 10). This unit consisted of a chain sling around the landing gear with auxiliary jacks to obtain initial clearance for flotation tires. Then a cable hoist accomplished additional elevation to clear jack bases. A study of forces follows, using the A4D aircraft as an example.

Plate 11 shows relative positions of opposing struts and cables which are employed to pull the lower ends of the struts together, thereby accomplishing elevation of an airplane wheel. Plate 12 shows the analysis of forces in the cable under a specified load and in different positions. Plates 13 through 17 show examples of the calculations made to determine forces given on Plate 12.

Plate 18 again shows relative positions of opposing struts and elevating cables, plus the effects of varying the position of a single element such as the pulley used to guide the cable on one of the struts. Plates 19 through 24 show wheel spacings and loadings for the airplanes under consideration.

This initial phase demonstrated that the maximum loads to be encountered could be effectively supported by a system of cables.

2. Selection of Flotation Tires

Aside from being functional, there are two basic requirements. The device must adapt dimensionally to the aircraft and it must offer adequate flotation. Obviously dimensional clearance can only be determined after selection of wheels and tires. Several types have been considered, including Terra-Tires, earth-mover and grader tires, airplane tires, sand tires, low platform trailer tires and conventional tires.

Terra-Tires have advantages of low pressures, large contact areas, and good load capacities. However, their large size, high weight and high cost prohibit their use.

Earth-mover and grader tires are not made in sizes small enough to be competitive. Low platform trailer tires are not only too heavy, but are inadequate as to ground contact area.

Airplane tires and wheels are generally quite expensive which would indicate their explicit use is unjustified. Dual tires are possibly adaptable, but would cause considerable dimensional difficulties.

The following is a listing of aircraft being considered and their relative wheel loadings (Refer to Plates 19 through 24)

CRAFT	STATIC WG. LBS.	NOSE WGT. LBS.	MAIN GEAR WGT. (EACH) LBS.
A4D	19,900	3,430	8,235
F4D	24,455	3,355	11,050
F8U-1	26,810	4,130	11,340
F8U-2	27,990	4,890	11,550
A2F	50,644	7,038	21,481
F4H	58,000	8,400	25,300

The low airplane silhouettes and the small ground clearances under optional stores dictates the use of the smallest possible tires on flotation devices. Furthermore, under the SATS program, such devices may often be airborne and the wheels and tires must therefore be as light as possible. In spite of these requirements, wheels and tires must be of sufficient size and rating to carry required loads.

From Plate 5 contact areas relative to load were selected for flotation on forward-area airfields.

Considering four wheels per dolly, the maximum wheel load would be approximately 6300 lbs.

Examples of tires and their load capacities are as follows:

TYPE	SAND	CONVENTIONAL	HELICOPTER	HELICOPTER
SIZE	9.00-15	9.00-16	11.00-12	11.00-12
DIAMETER	33.0	35.8	31.5	31.5
WIDTH	9.63"	10.19"	11.0"	11.0"
CAPACITY, LBS.	2,480	2,690	2,500	6,500
PRESSURE	25	20	18	51
CONTACT AREA	86	77	115	110
WEIGHT, LBS.	30	67	30	30

Tire data and specification, courtesy Goodyear Tire and Rubber Company.

From the above, it is obvious that the helicopter tire can have the smallest diameter, the lowest pressure and the largest contact area by considerable margins. The only wheels apparently available for such tires, however, are cast magnesium aircraft wheels which are quite expensive. Actual price quotation from tire and wheel manufacturers have been used to determine that a helicopter tire and wheel assembly will cost $150 to $160 more than a tire and wheel of the others listed. If twelve tires are used, as contemplated in the concept proposed, each complete transporter kit would thus cost approximately $2,000 more if helicopter tires are used exclusively. This price of course is for prototype quantity, and would be totally unrelated for production units.

The conventional 9.00-16 tires are least subject to puncture, but they have the largest diameter and the smallest contact area. Furthermore, the 9.00-16 tire installed weighs at least 60 lbs. more than a 9.00-15 sand tire installed. Again, figuring twelve wheels are used, each complete transporter kit would weigh almost 750 lbs. more.

When the larger planes are considered, the main wheel loadings are approximately 25,000 lbs. Assuming this load is to be carried on four wheels, each of those wheels must support about 6300 lbs. Such a load cannot possibly be carried by either the 9.00-15 sand tire or the 9.00-16 conventional tire. A larger tire, which in any style would be 48 inches diameter, would support the load, but obviously it would be too large for physical clearance. The 11.00-12 helicopter tire, however, with a tire pressure of 51 psi, will carry the 6,500 lb. load for short distances at speeds of not over 5 mph. Unfortunately the ground contact area of each helicopter tire is only 75 percent of the minimum requirement for the F4H, as determined from Plate 5 of Miscellaneous Paper No. 4-459.

The nose wheel loadings in all cases are less then 10,000 lbs. and it would be possible to use smaller sizes of tires than those under consideration. There would be very little saving of either weight or cost if this were done, and it is possible that the benefits of standardization would outweigh whatever differences that might be achieved. Furthermore, the larger tires will provide a higher degree of flotation, which is particularly desirable with the lead or nose wheels.

It would be normally recommended that 9.00-15 sand tires, inflated to 25 psi, be used on all wheel transporters, with the exception of the main gear of both heavier planes. But for purposes of simplicity and uniformity, one tire is recommended for all wheels. All wheel transporters will require 11.00-12 helicopter tires, inflated to 51 psi. For the main gear of heavier planes, namely the A2F and F4H, auxiliary methods must be utilized for added flotation.

All of the above recommendations are in accord with the findings of Technical Report 3-554 in that tire pressures are quite low in comparison with those usually associated with airplane tires. These recommendations, for the most part, substantially exceed the minimum ground contact area requirements established on Plate 5 of Miscellaneous Paper No. 4-459.

3. Clearance Study

This portion of study consisted of making detailed examination of the aircraft landing gear and structural drawings. From these drawings were determined gear and structural clearances, weights and centers of gravity, allowable stresses and configurations. Certain flight areas were visited to verify positions and shapes of stores and other critical or pertinent dimensions.

Using the preceding tire and flotation data, the elements of the concept were plotted on the sketches of the various planes and the interferences noted. On the F4D, indicated stores made it necessary to elevate the plane excessively. This is not desirable because of extra time required, the expense of high-lift jacks, and general aircraft instability.

Store positions for the F4H verified that no tire could be used larger than the 11.00-12 helicopter tire.

For the F8U, arrangement of the contilevered nose gear made attachment awkward and indicated need for a special carrier. The arrangement of the flap related to the main gear on the F4H presented the most difficult problem of all, particularly in view of planning a carrier frame which might be used interchangeably.

This apparent interference of stores on some of the planes and of landing gear elements on others prompted an immediate review of the basic concept. It was concluded that the upper carrier frame, as originally proposed, could not be utilized. This problem was considered and it was concluded that a two-piece bottom-mounted carrier, without carrier chains could and should be substituted. These could be two rigid members, with the lower portion roughly conforming to the shape of the airplane tires and the upper ends consisting of arms to which transporter struts are attached. Elimination of the jacks and the necessity of initial elevating was now possible. Careful analysis indicated this was both feasible and desirable.

The two parts of the bottom carriers must still be linked after being placed, before elevation can be accomplished. In addition, the bottoms of these would be cross-connected in order to pull toward each other, thereby firmly supporting the airplane tire during elevation. This cross-connection will also provide stops on the bottom members so that motions toward each other will be limited. (See Plate 25)

The bottom surface of the carriers will actually be skid-like devices. Under extremely soft or muddy conditions, which do not provide sufficient flotation even with the proposed tire augmentation, the skids would become operative and at least double the ground contact area. This would be undesirable if t... wheels were self-powered, but because the whole assembly is to be towed, total flotation will be greatly improved. In addition, added flotation is now available for the F4H when operated from muddy fields.

The front transporter units, for attachment to aircraft nose wheels, while being different from the rear units, which attach to the main aircraft wheels, can be identical for all planes, regardless of weight. This is provided the bottom carrier is designed to fit both single and dual nose wheels. The carrier is therefore notched to guide single wheels, the dual wheels being self-guiding. If it is not considered necessary to have rear transporters interchangeable for the two weight classes, those for the smaller aircraft could be lighter and faster.

With use of the bottom carrier and eliminating auxiliary jacks, the attachment and elevation of the transporter units become simplified. The front and rear sections of a unit can be wheeled into place quite simply with their respective carrier sections attached. The struts would act as handles. The struts would then be flipped over so that the carrier bottoms are near the plane tire. The carriers would be snapped together, the elevating cables attached and front and rear sections brought together to elevate the particular airplane wheel. It is proposed that elevation be accomplished with a hydraulic actuator through a cable system. This actuator would be powered from an accumulator, precharged by a hand pump. By this method, elevation can be completed in time lapses measured in seconds. After all three units are in place, adjustable connecting bars can be pinned in place and the airplane is ready to be towed. This is accomplished without mechanical connections to the airplane and should be possible under adverse weather conditions or in high stress situations.

With the changes that are recommended, the transporter has become even more simple and lighter in weight. The feature of being reducible to kit form has been carefully maintained. A complete transporter assembly consists of three individual units, inter-connected with three adjustable-length, tubular bars. Each individual unit in turn consists of a two-piece carrier, a front section and a rear section. Each section consists of a carrier half, two wheel assemblies, and one strut frame. Each wheel assembly consists of one wheel, one tire and a stub axle.

Little, if any, maintenance should be necessary, except to keep the tires inflated and the elevating cables in good condition. The simplicity of construction also keeps cost and weight to a minimum. The only expensive items are airplane-type tires and their special wheels; this cost should be a factor only for prototype quantities.

4. Development of an Alternate Method

The tire selected will not provide,for heavier aircraft (namely the A2F and the F4H), full flotation requirements. On extremely soft fields the main gear carriers will be forced to act as skids. Carriers for all other gears will, of course, maintain more than adequate flotation. Though this is certainly operational and adequate, it is definitely not an optimum device for two reasons:

1. A forward-area airfield, as previously defined, is not the worst possible field condition. The worst condition is encompassed by an area having ground structure capable only of supporting walking personnel and tractive equipment. That is, supported load versus supporting area should define a ground pressure of less than 15 pounds per square inch.

2. This method of flotation can evolve high towing forces, which in turn can dictate massive towing devices. In some cases the towing effort could be such that the towing device could not be transported to the field. The least ground pressure will define the least ground penetration; neglecting extraneous factors, the depth of penetration relates directly with developed towing force. (See Section V, "Steering Methods and Towing Forces for Flotation".)

In seeking an improved means of load support, the following were basic requirements:

1. Maximum ground contact area.
2. Rolling action for minimum mechanical effort.
3. Use of beneficial aspects of proposed dollies.
4. Reliability and economy.

To provide maximum contact area without structure or stores interference, and to maintain a rolling action, describes a specific shape or outline. This is basically an ellipsoid having its major axis fixed in a fore and aft direction, and its periphery flexible to maintain this direction. Specifically, this describes flexible, continuous tracks over fixed, load-carrying guide wheels. This is described on Plate 48. Actually the mechanism consists of the original carrier with multiple V-belt treads substituted for wheels and tires. The supporting wheels and V-belts, on opposing sides of the same carrier, rotate independently. Also, two of the flotation tires are retained on the forward side of the nose wheel carriage (where loading is minimum). These two features facilitate steering and tracking. To guard against soil and gravel contamination, belt wipers are installed as shown, with no open areas within the track. As to load capacity, the treads offer, with optimum clearance conditions, approximately five times the former contact area. Maximum ground pressure is now approximately 14 pounds per square inch.

Thus, all the benefits of tire flotation have been maintained, but operation is now possible under the worst possible field conditions.

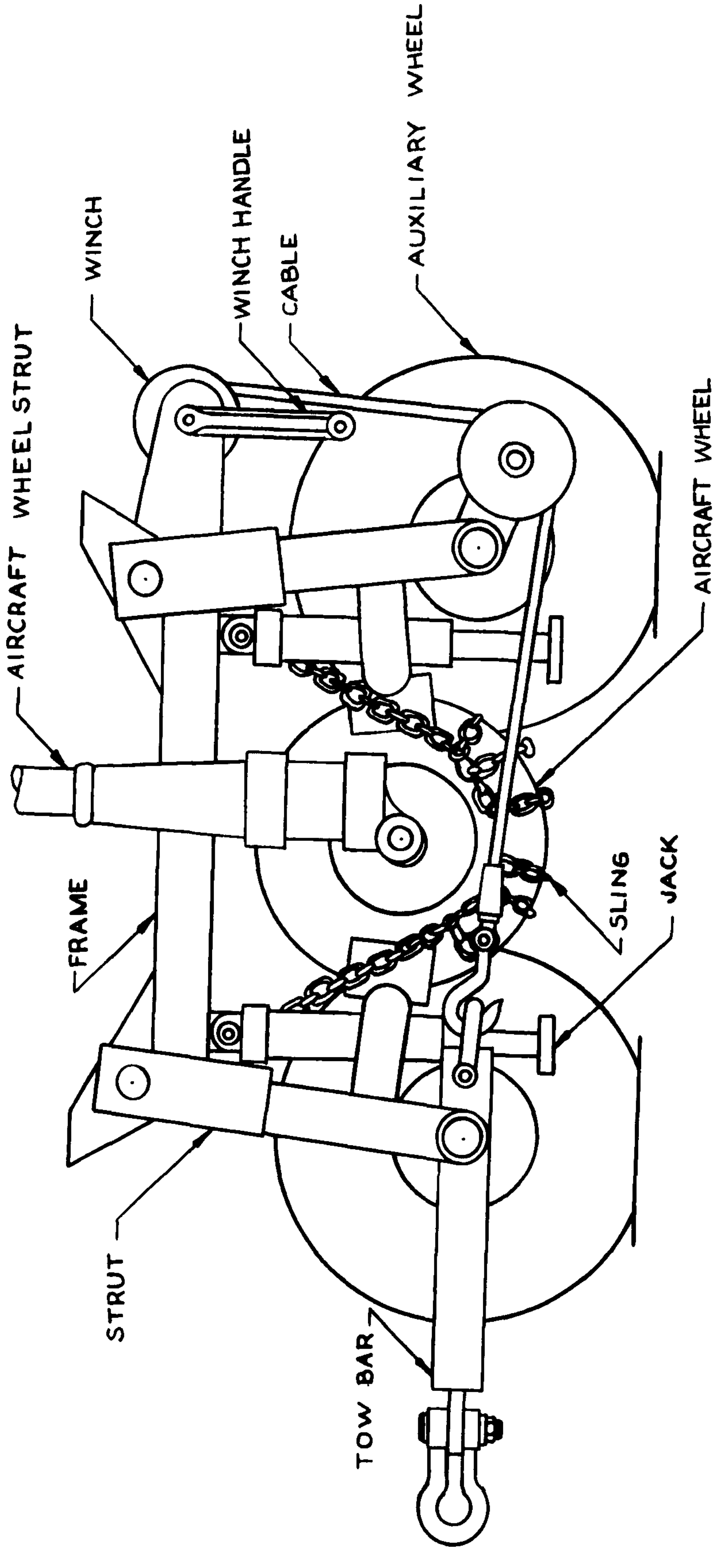
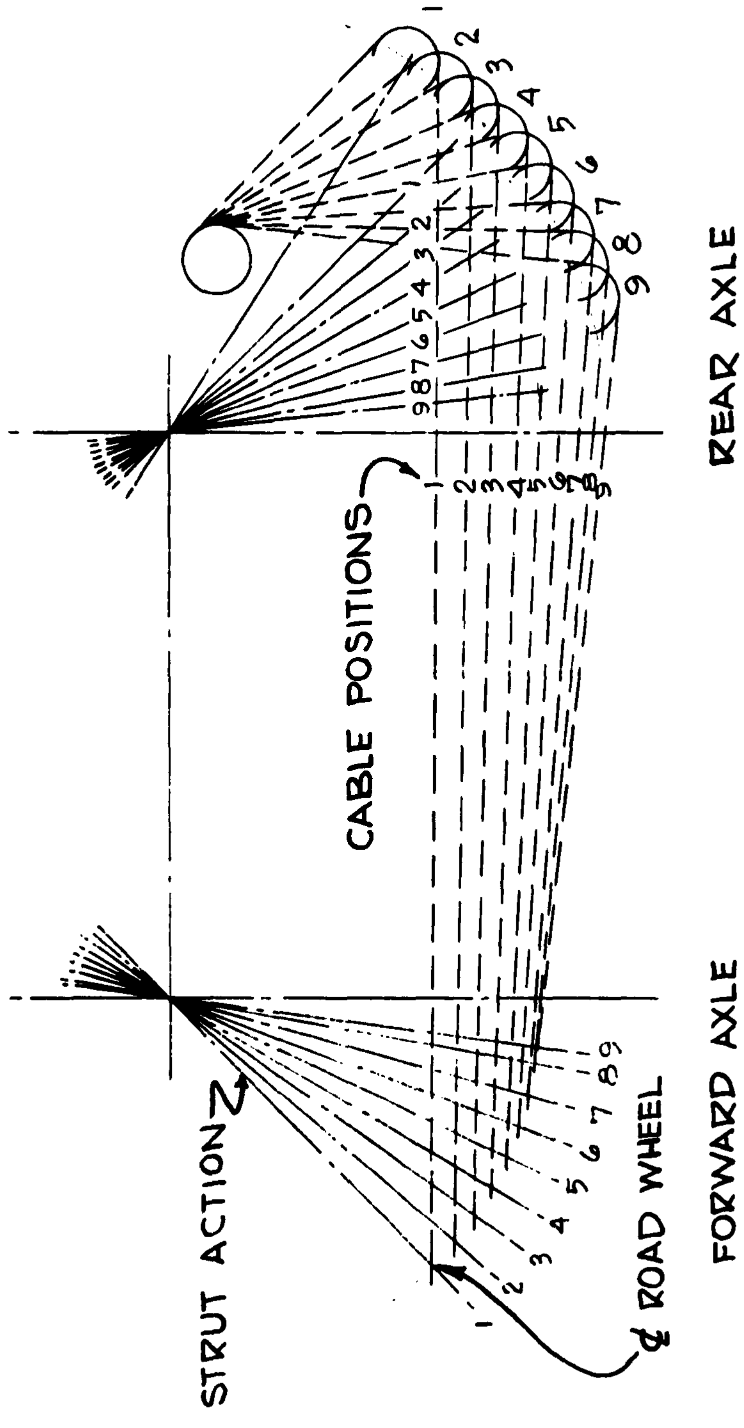


PLATE 10. DOLLY CONCEPT ORIGINALLY PROPOSED FOR AIRCRAFT TRANSPORT

AIRCRAFT TRANSPORTER

PRELIMINARY DATA

CABLE LIFT ACTION: (SINGLE CABLE)



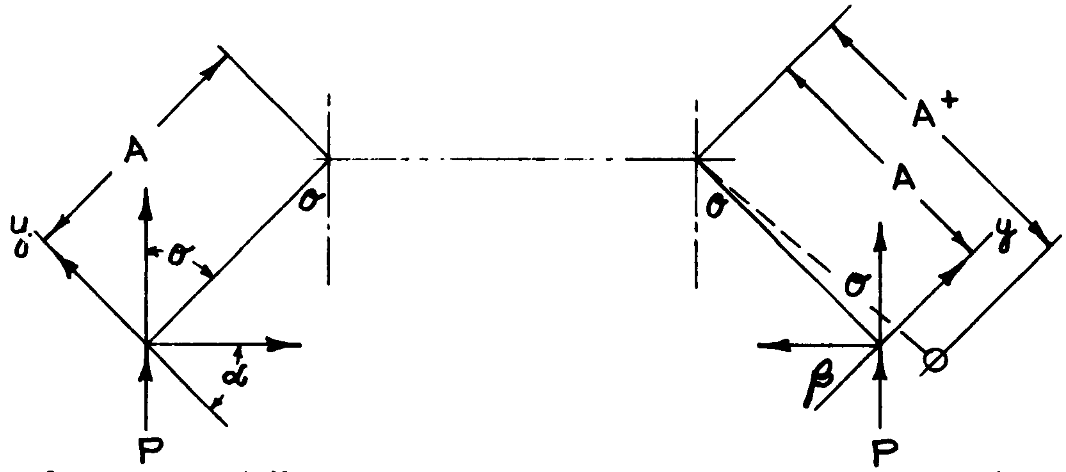
MAIN WHEEL UNIT

PLATE 11

AIRCRAFT TRANSPORTER
PRELIMINARY DATA

ANALYSIS OF CABLE FORCES

A4D AIRCRAFT - MAIN WHEEL UNIT



CONDITIONS:

P= 4118 LBS   SINGLE PART LINE

IGNORE MA OF ACTUAL CABLE ARM (A+)

ANGLE β TAKEN IN RESPECT TO STRUT

POSITION	σ	α	β	y	CABLE T1	CABLE T2	TOTAL CABLE TENSION
1	45°	45°	46°	2,911	4,118	4,194	8,312
2	40°	38°	41°	2,643	3,402	3,505	6,907
3	35°	33°	36°	2,359	2,815	2,915	5,730
4	30°	28°	32°	2,059	2,334	2,428	4,762
5	25°	23°	27°	1,748	1,889	1,950	3,839
6	20°	17°	23°	1,408	1,472	1,530	3,002
7	15°	11°	19°	1,002	1,082	1,134	2,216
8	10°	5°	15°	712	714	737	1,451
9	6°	1°	13°	428	428	439	867

PLATE 12

AIRCRAFT TRANSPORTER

PRELIMINARY DATA

A 4 D

CALCULATIONS:

POSITION 1.

$$y = 4118 \times \cos 45^\circ$$
$$= 4118 \times .707$$
$$= 2911 \text{ LB}$$

$$T_1 = \frac{y}{\cos 45^\circ} = \frac{2911}{.707} = 4118 \text{ LB}$$

$$T_2 = \frac{y}{\cos 46^\circ} = \frac{2911}{.694} = 4194 \text{ LB}$$

POSITION 2.

$$y = 4118 \times \cos 50^\circ$$
$$= 4118 \times .642$$
$$= 2643 \text{ LB}$$

$$T_1 = \frac{y}{\cos 39^\circ} = \frac{2643}{.777} = 3402 \text{ LB}$$

$$T_2 = \frac{y}{\cos 41^\circ} = \frac{2643}{.754} = 3505 \text{ LB}$$

PLATE 13

AIRCRAFT TRANSPORTER

PRELIMINARY DATA

A 4 D

POSITION 3.

$$y = 4118 \times \cos 55^\circ$$
$$= 4118 \times .573$$
$$= 2359$$

$$T_1 = \frac{y}{\cos 33^\circ} = \frac{2359}{.838} = 2815 \text{ LB}$$

$$T_2 = \frac{y}{\cos 36^\circ} = \frac{2359}{.809} = 2915 \text{ LB}$$

POSITION 4.

$$y = 4118 \times \cos 60^\circ$$
$$= 4118 \times .500$$
$$= 2059 \text{ LB}$$

$$T_1 = \frac{y}{\cos 28^\circ} = \frac{2059}{.882} = 2334 \text{ LB}$$

$$T_2 = \frac{y}{\cos 32^\circ} = \frac{2059}{.848} = 2428 \text{ LB}$$

PLATE 14

AIRCRAFT TRANSPORTER

PRELIMINARY DATA

A 4 D

POSITION 5.

$$y = 4118 \times \cos 65^\circ$$
$$= 4118 \times .422$$
$$= 1738 \text{ LB}$$

$$T_1 = \frac{y}{\cos 23^\circ} = \frac{1738}{.920} = 1889 \text{ LB}$$

$$T_2 = \frac{y}{\cos 27^\circ} = \frac{1738}{.891} = 1950 \text{ LB}$$

POSITION 6.

$$y = 4118 \times \cos 70^\circ$$
$$= 4118 \times .342$$
$$= 1408 \text{ LB}$$

$$T_1 = \frac{y}{\cos 17^\circ} = \frac{1408}{.956} = 1471 \text{ LB}$$

$$T_2 = \frac{y}{\cos 23^\circ} = \frac{1408}{.920} = 1530 \text{ LB}$$

PLATE 15

AIRCRAFT TRANSPORTER

PRELIMINARY DATA

A 4 D

POSITION 7.

$$y = 4118 \times \cos 75^\circ$$
$$= 4118 \times .258$$
$$= 1062 \text{ LB}$$

$$T_1 = \frac{y}{\cos 11^\circ} = \frac{1062}{.981} = 1082 \text{ LB}$$

$$T_2 = \frac{y}{\cos 19^\circ} = \frac{1062}{.945} \quad 1134 \text{ LB}$$

POSITION 8.

$$y = 4118 \times \cos 80^\circ$$
$$= 4118 \times .173$$
$$= 712 \text{ LB}$$

$$T_1 = \frac{y}{\cos 5^\circ} = \frac{712 \text{ lb}}{.996} = 714 \text{ LB}$$

$$T_2 = \frac{y}{\cos 15^\circ} = \frac{712}{.965} = 737 \text{ LB}$$

PLATE 16

A I R C R A F T   T R A N S P O R T E R

P R E L I M I N A R Y   D A T A

A 4 D

POSITION 9.

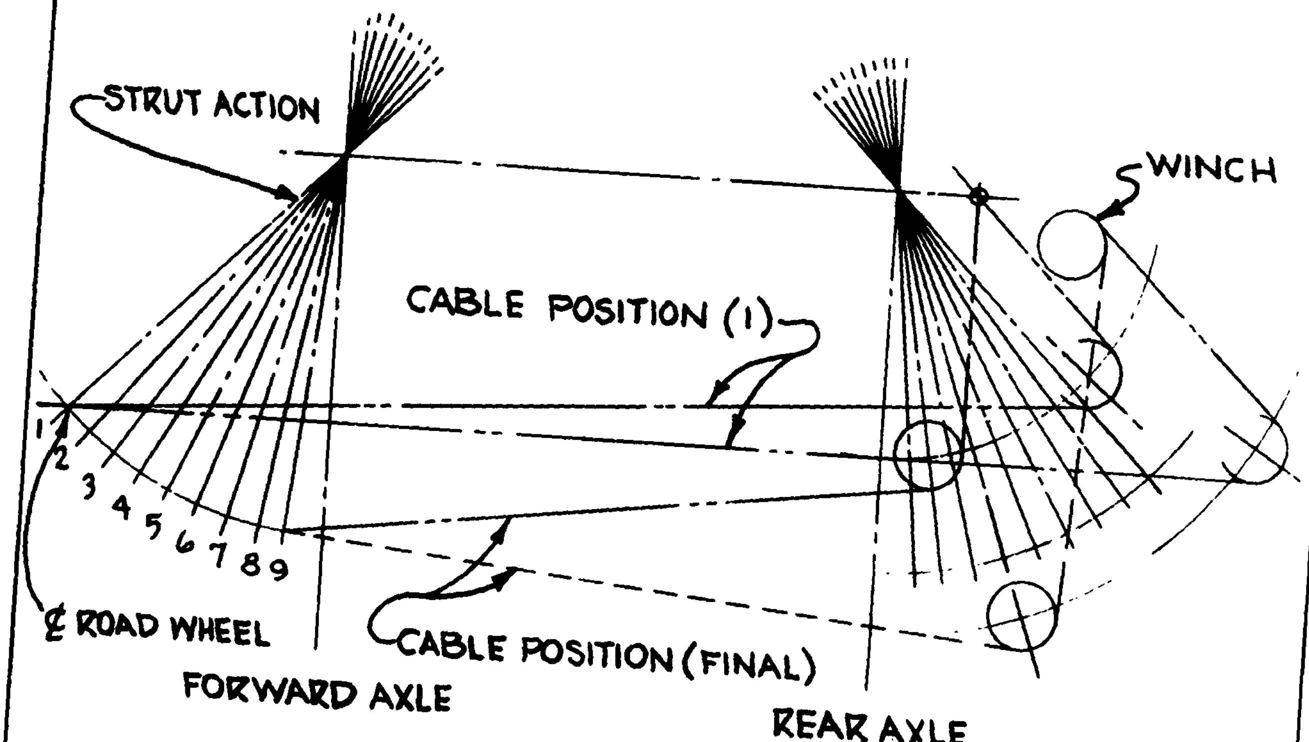
$$y = 4118 \times \cos 84^\circ$$
$$= 4118 \times .104$$
$$= 428 \text{ LB}$$

$$T_1 = \frac{y}{\cos 1^\circ}$$
$$= \frac{428}{.999}$$
$$= 428 \text{ LB}$$

$$T_2 = \frac{y}{\cos 13^\circ}$$
$$= \frac{428}{.974}$$
$$= 439 \text{ LB}$$

PLATE 17

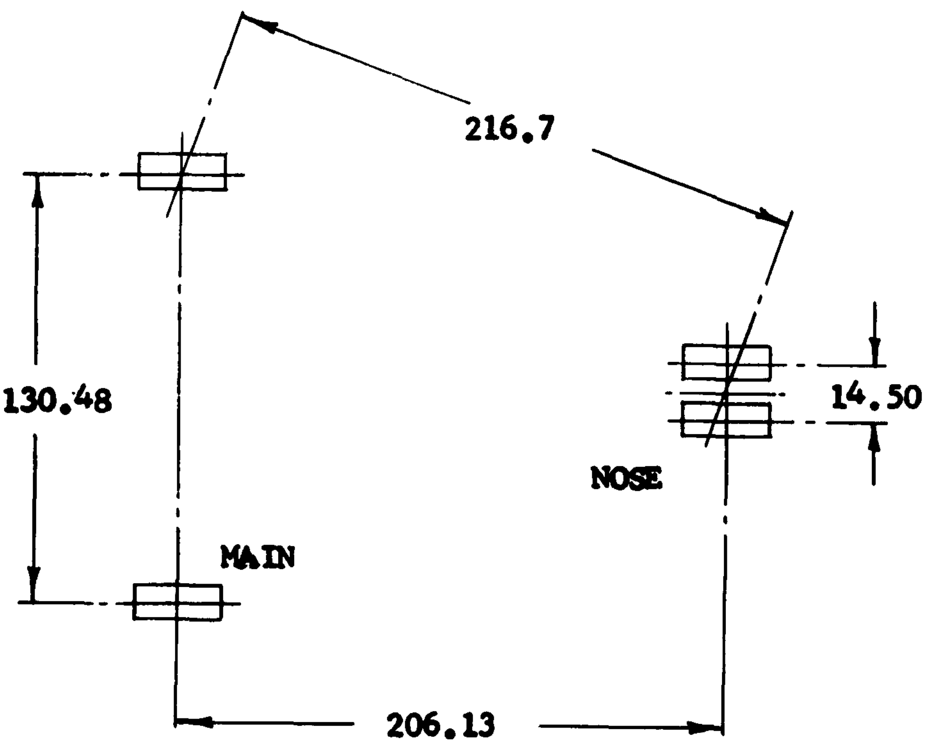
AIRCRAFT TRANSPORTER
PRELIMINARY DATA



MAIN WHEEL UNIT

PLATE 18

AIRCRAFT TRANSPORTER
PRELIMINARY DATA
A2F1



TIRE DATA:

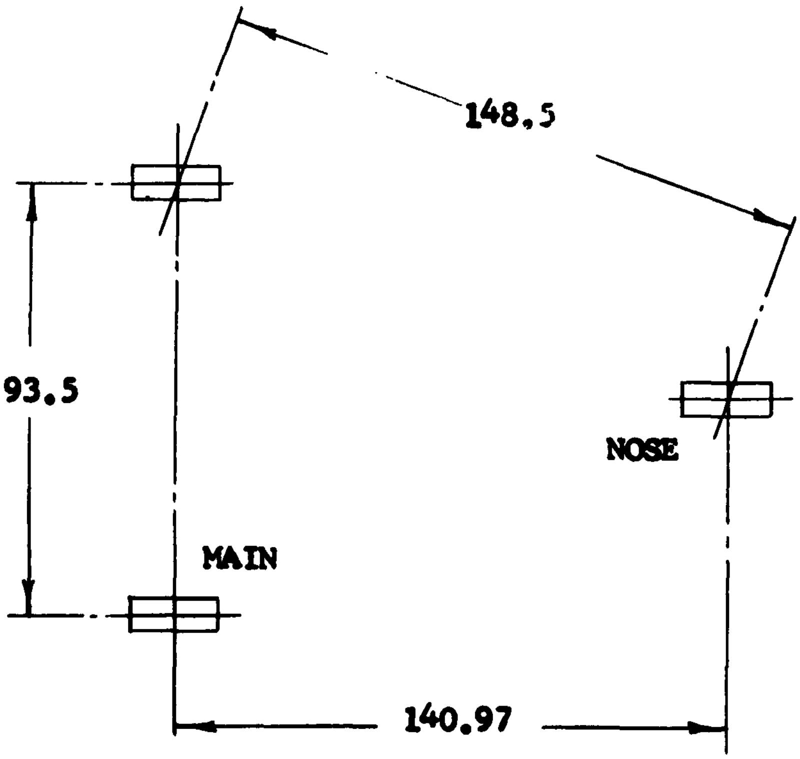
MAIN	35	O.D.	NOSE	19.5	O.D.
	11	WIDE		5.5	WIDE
	14.9	L.R.		9.0	L.R.

LOAD CONDITIONS:

TOTAL STATIC = 50,644 LB
MAIN WHEEL (EA) - 21,481 LB
NOSE (TOTAL) = 7,038 LB

PLATE 19

AIRCRAFT TRANSPORTER
PRELIMINARY DATA
A4D



TIRE DATA:

MAIN 24 O.D.
5.5 WIDE
10.6 L.R.

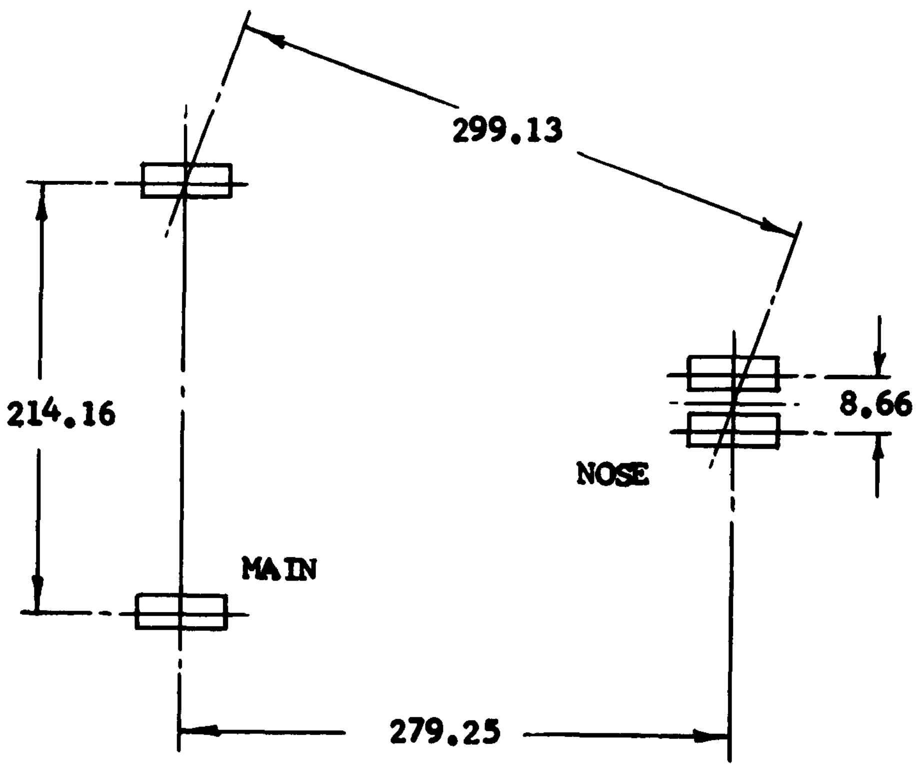
NOSE 18 O.D.
5.5 WIDE
7.6 L.R.

LOAD CONDITIONS:

TOTAL STATIS = 19,900 LB
MAIN (EA) = 8,235 LB
NOSE = 3,430 LB

PLATE 20

AIRCRAFT TRANSPORTER
PRELIMINARY DATA
F4H



TIRE DATA:

MAIN	30 O.D.	NOSE	18 O.D.
	7.7 WIDE		5.6 WIDE
	13.42 L.R.		8.3 L.R.

LOAD CONDITIONS:

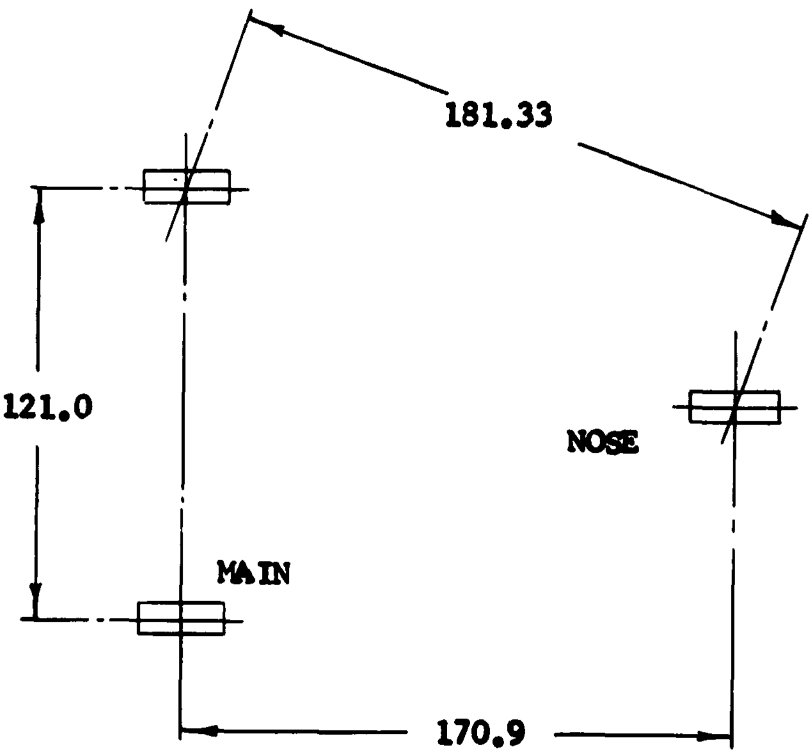
TOTAL STATIC = 58,000 LB

MAIN WHEEL (EA) = 25,300 LB

NOSE (TOTAL) = 8,400 LB

PLATE 21

AIRCRAFT TRANSPORTER
PRELIMINARY DATA
F4 D



TIRE DATA:

MAIN 26 O.D.
6.6 WIDE
11.2 L.R.

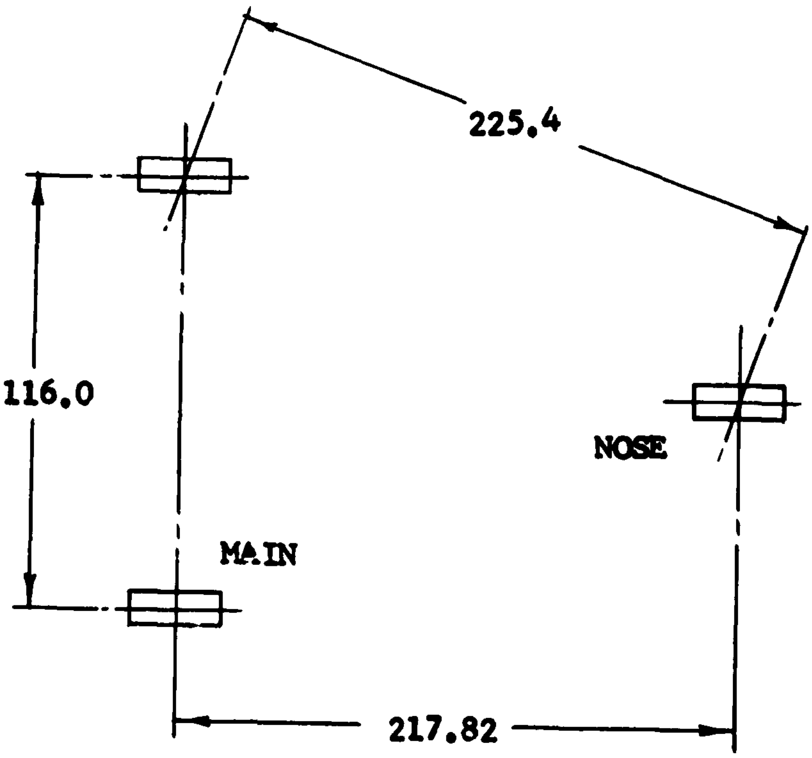
NOSE 22 O.D.
5.5 WIDE
9.86 L.R.

LOAD CONDITIONS:

TOTAL STATIC = 25,455 LB
MAIN (EA) = 11,050 LB
NOSE = 3,355 LB

PLATE 22

AIRCRAFT TRANSPORTER
PRELIMINARY DATA
F8U2



TIRE DATA:

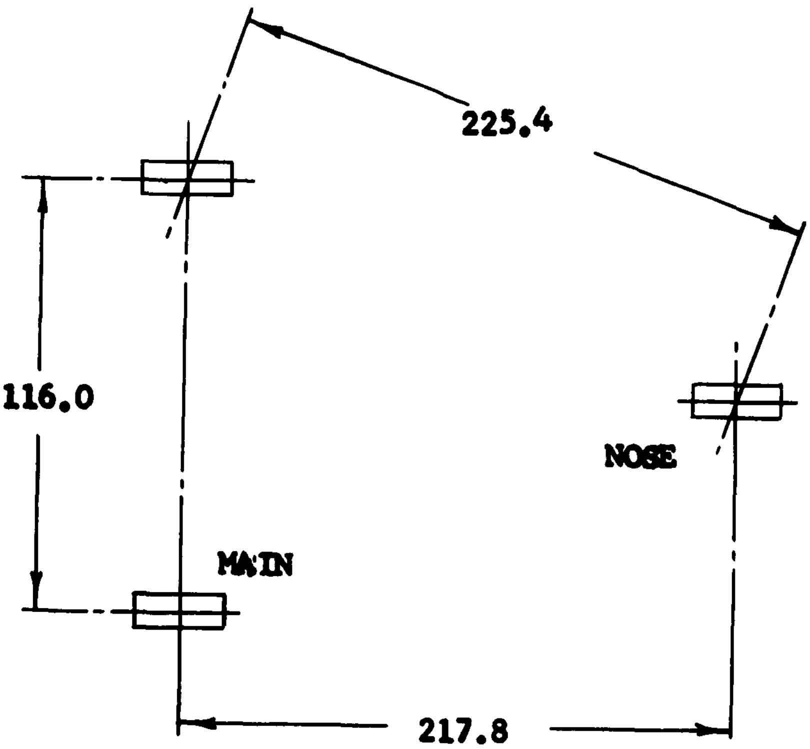
MAIN	26	O.D.	NOSE	22	O.D.
	6.6	WIDE		5.5	WIDE
	9.3	L.R.		8.0	L.R.

LOAD CONDITIONS:

TOTAL STATIC = 27,990 LB
MAIN = 11,550 LB
NOSE = 4,890 LB

PLATE 23

AIRCRAFT TRANSPORTER
PRELIMINARY DATA
F8U1



TIRE DATA:

MAIN	26 O.D.		NOSE	22 O.D.
	6.6 WIDE			5.5 WIDE
	9.3 L.R.			8.0 L.R.

LOAD CONDITIONS:

TOTAL STATIC = 26,810 LB

MAIN (EA) = 11,340 LB

NOSE = 4,130 LB

PLATE 24

V. STEERING METHODS AND TOWING FORCES

1. Steering Methods

Correct steering geometry is advisable to prevent induced stresses in flotation members and limit transferring those stresses to the aircraft. Because of widely varying distances for the group of aircraft, a strictly correct geometry is not possible. But by holding rigidly the landing gear centers, stresses will be absorbed by carriers alone. Thus, essentially, an average geometry was selected, with the need only to limit wearing of flotation equipment.

The nose wheel dolly is considered a single vehicle; that is, lines drawn through the front wheel pivots would intersect at the center of the rear wheel axle (see Plate 26). This geometry is based upon Ackerman Steering Principles, the basic tenet of automotive steering, and of course determines approximate wheel base. On rear dollies, wheel axles are as short as possible, in attempting to approach single-wheel action. Since landing gear centers shall be fixed points, rear wheels shall rotate at differing speeds, and so are independently suspended. From the foregoing, rigidly held landing gear centers make some scuffing inevitable. This action is distributed over the eight rear tires. If the entire system were treated as a single vehicle, the two rear nose wheels would wear rapidly.

The above criteria applies equally to tread systems, considering treads are to be individually mounted.

With reference to towing connections (see Plate 27), these are adjustable, tubular rods which, when pinned, form a rigid frame. The single pivoting point is at the front axle of the nose dolly.

2. Towing Forces

Care must be taken that necessary towing force cannot exceed capabilities of field equipment. Since ground capabilities fluctuate constantly, a basically functional field can degenerate to a very poor strength condition. Dependent upon personal judgement, the field may be considered operable if ground strength supports towing equipment and personnel. This ground strength is less than half the capability of fields for which this program was intended, and for which flotation tires were selected. However, because this marginal operating condition can possibly exist, comparison of towing forces should be made relative to these conditions.

Three papers were selected which analyze rolling resistance of tires and tracks for various ground conditions. They were the following:

1. "Track and Wheel Evaluation"
   M. G. Bekker, U.S. Army Ordnance
2. "Thrust for Propulsion"
   M. G. Bekker, U.S. Army Ordnance
3. "Mechanics of Vehicles"
   J. J. Taborek, Towmotor Corp., Cleveland

For extremely soft ground areas, treads are decidedly superior to tires, both for sinkage (degree of flotation loss) and for towing force. This is because possible contact area is limited for tires (due in part to aircraft space limitations), but can be expanded greatly for treads.

Consider the following relationships:

Sinkage is a function of: $\frac{W}{2bl}$

Rolling resistance is a function of: $\frac{b^n}{l^{n+1}} \cdot W$

Where: n is a soil constant

b is width of contact

l is length of contact

W is weight of vehicle

It is immediately evident that, for a given ground condition, sinkage is in reverse proportion to contact area. But rolling resistance reduces with smaller widths and greater lengths. It follows that a flotation tire should be of large diameter and of reduced width. Actually this reduces compacted ground area and thus work done in rotating.

The contact area of the proposed tires is about one-fifth of the area of proposed treads. Thus in the identical soft soil, sinkage of tires versus treads would be approximately a factor of five. The ratio of rolling resistances would be much greater because of the exponential factors and the limited ratio of tire width to length.

For a range of ground conditions defined for this program, towing force for treads would range, approximately, from 1500 pounds to 12,000 pounds; for tires, from 1000 pounds to 16,000 pounds. However, for a marginal field condition, not actually covered by this program, but certainly conceivable as existing, the tread towing force could reach 15,000 pounds. But this force for tires would reach three to four times that value.

Therefore, consideration should be given as to the worst possible operating field condition, even if related only to mis-parked and subsequently mired vehicles.

The following are basic conclusions:

1. For airfield conditions as defined for this program, flotation tires are adequate.

2. For the conceivable worst ground conditions, treads are far superior to tires, both for flotation and for reduced towing effort.

VI. DISCUSSION OF RESULTS AND CONCLUSIONS

Dimensional clearances of the external stores and alighting gear structure of the aircraft analysed necessitated modification to the flotation concept as originally proposed (see Plate 10).

The new concept as depicted on Plate 25 and Plate 26 has proved to be far superior in several important respects.

The device consists of independent fore and aft shoe or chock assemblies pivotally mounted to the frame and axle assembly that carries the two wheels. To move the aircraft the fore and aft dolly assemblies are individually positioned at each aircraft wheel. The fore and aft units are then inter-connected by two shoe plate tension bars that are pinned in place. The forward shoe cable is then hooked to the aft assembly. A hydraulic actuator powered from a precharged accumulator retracts the cable to automatically raise the aircraft and position the dolly under the aircraft wheel. Elevation can be accomplished in less than 5 seconds. The three dollies are then inter-connected by the spacer bars and the aircraft is ready for towing.

In the analysis of towing forces associated with the ground conditions, it became apparent that self-cleaning caterpillar tracks are far superior to wheels for flotation under more adverse soil conditions.

Although the wheeled dollies presented in this study will provide the minimum degree of flotation required under soil conditions expected at forward-area fields, the vast superiority shown by tracks in the areas of improved flotation and reduction in towing forces warrent close consideration. The track dolly shown on Plate 48 is basically the same as the wheeled dolly except for the replacement of wheels by tracks. In view of much lighter loading on the nose dolly and to facilitate steering, it is planned to maintain the two wheels on the forward section of this dolly.

There are several basic advantages of the dolly concept as discussed in this report. Among them are:

1. Light weight and minimum stowed volume for transport to airfield.
2. Little or no stresses transferred to landing gear.
3. No mechanical connection to landing gear.
4. Simplicity and speed of operation.
5. Little maintenance of parts.
6. Elevated stability of aircraft.
7. Reasonable towing forces.
8. Adequate flotation.
9. With tracks, superior flotation and minimum towing force.
10. Simplicity of design.

As described in this report the dolly concept proves to be a highly feasible and efficient way to transport aircraft of the types defined over unprepared fields. Light weight, ease of application and good mobility are the major features of the design. The decision whether to go to the wheel type or the track type will depend on further definition of the operating conditions. Either type will prove highly effective, the tracked unit being able to operate under very adverse conditions.

It is suggested in view of the tremendous possibilities of the device that prototype hardware be manufactured for testing under actual field conditions, to prove the basic concept and define areas of improvement.

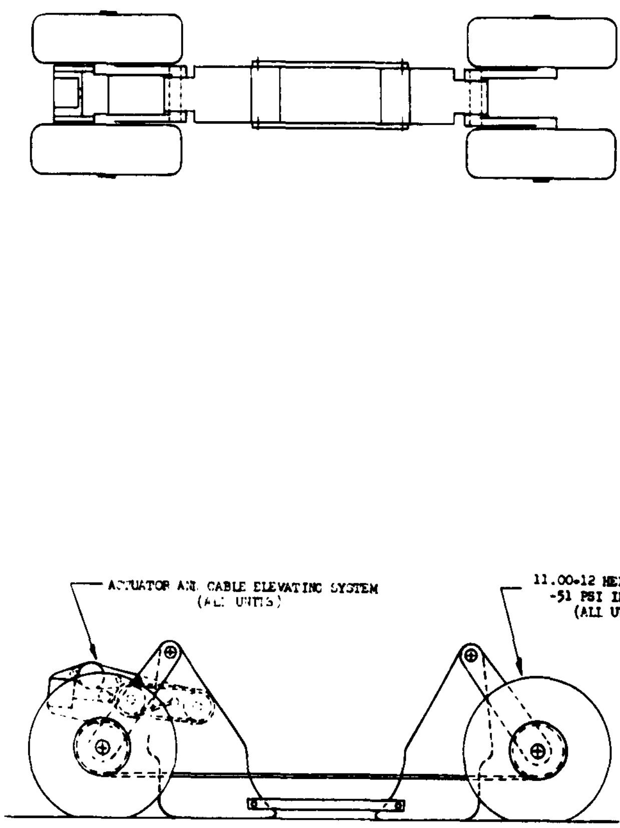


PLATE 25. FLOTATION DOLLY FOR MAIN GEAR OF AIRCRAFT
TYPES A2?, A4D, F4D, F4H, F8U-1 AND F8U-2
(SCALE: 1:40)

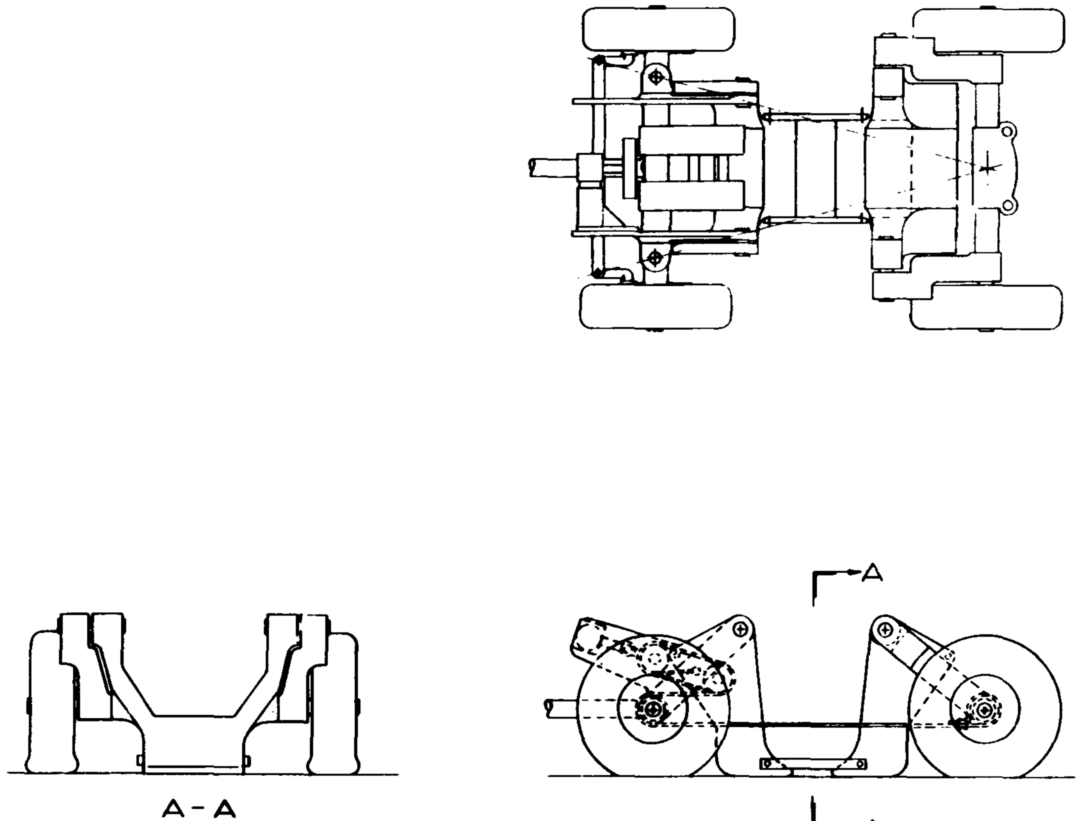


PLATE 26. FLOTATION DOLLY FOR NOSE GEAR OF AIRCRAFT TYPES A2F, A4D, F4D, F4H, F8U-1 AND F8U-2 (SCALE: 1/40)

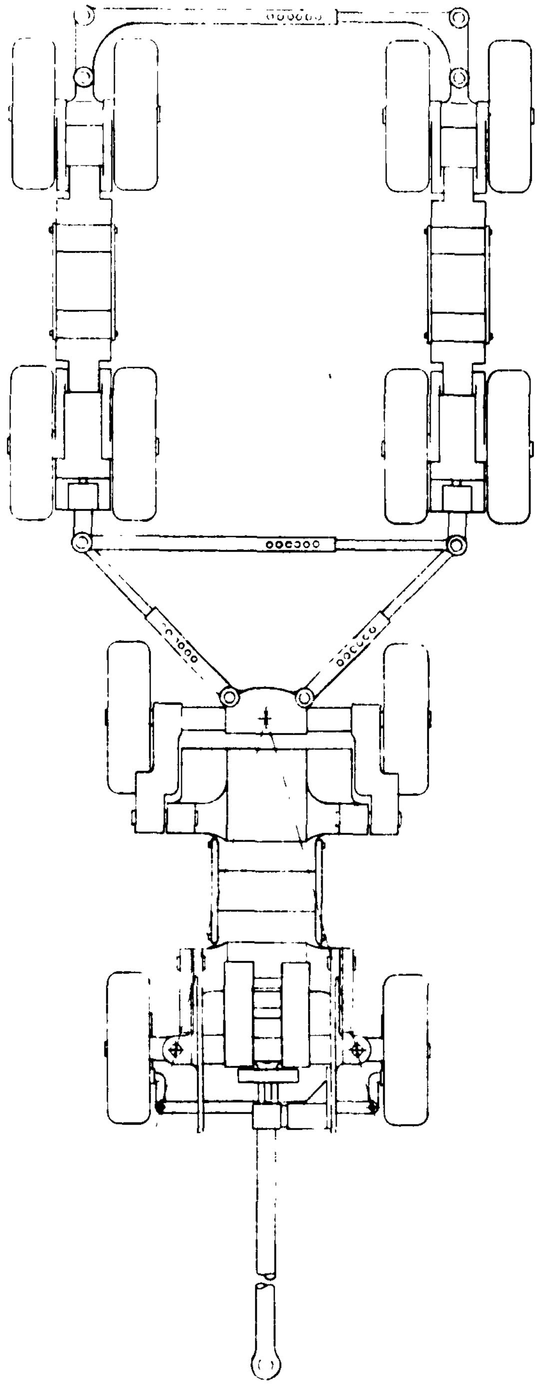


PLATE 27. FLOTATION DOLLIES IN POSITION FOR TOWING
(SHOWN FOR AIRCRAFT TYPE [illegible])
(SCALE: 1/4)

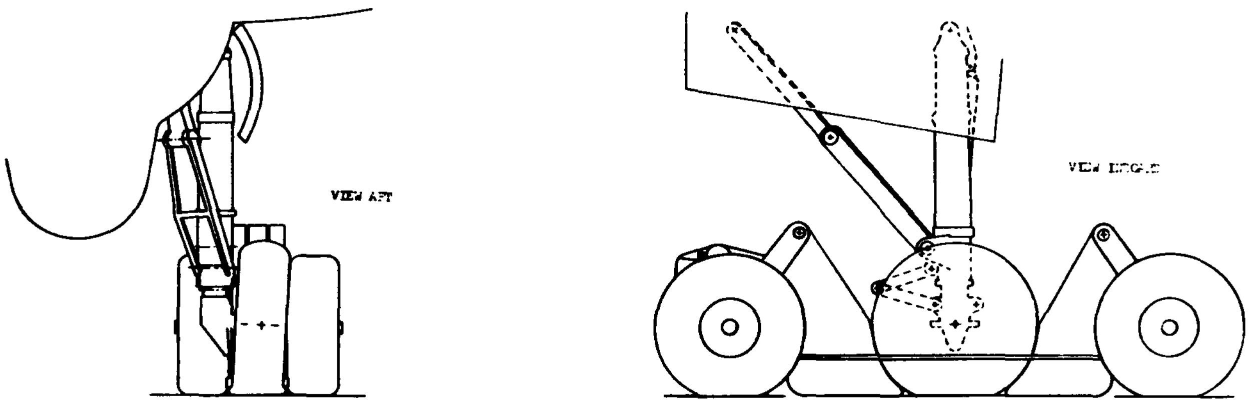


PLATE 28. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE A2F IN GROUND POSITION (SCALE: 1/40)

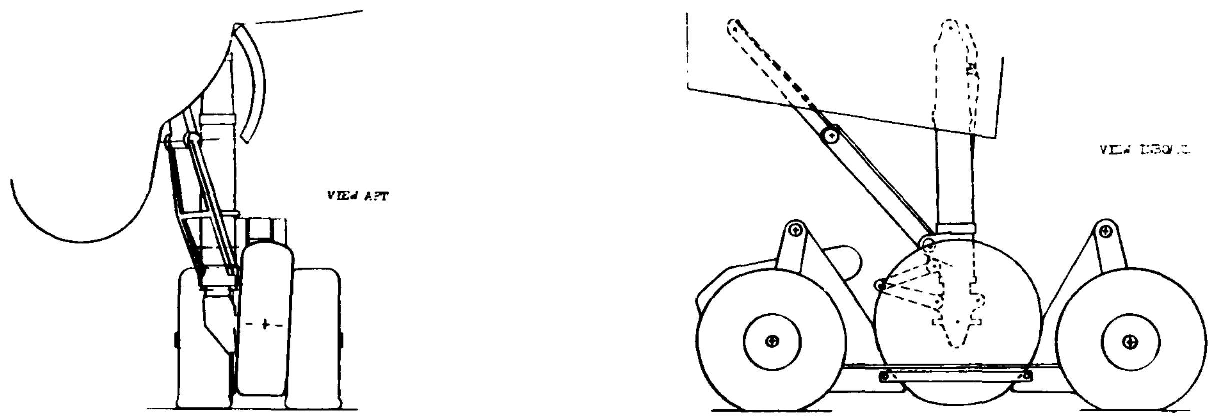


PLATE 29. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE A2F IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

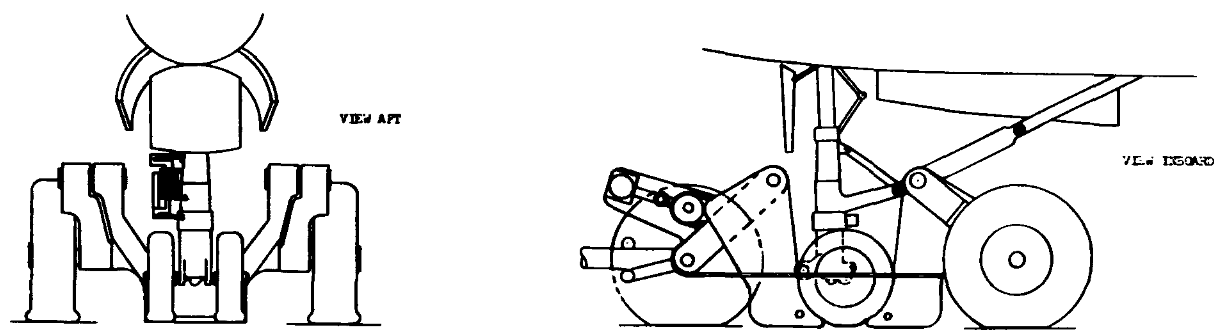


PLATE 30.- NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE A2F IN GROUND POSITION. (SCALE: 1/40)

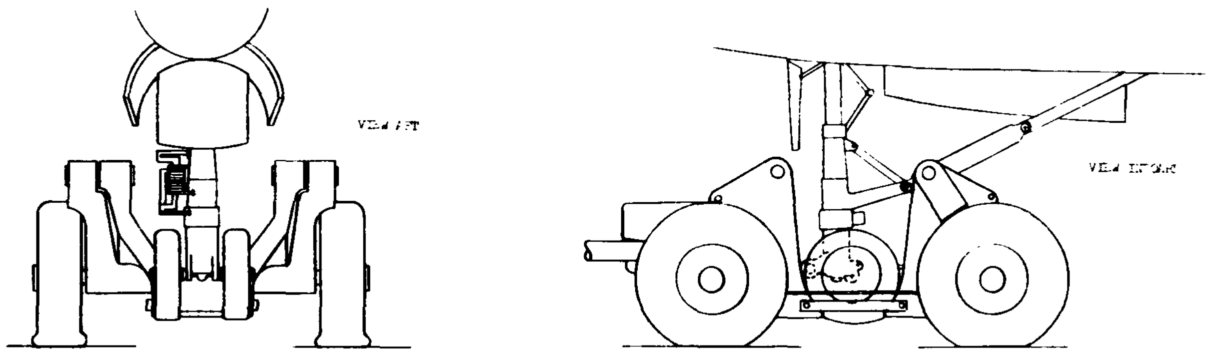


PLATE 31. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE A2F IN ELEVATED AND TOWING POSITION.
(SCALE: 1/40)

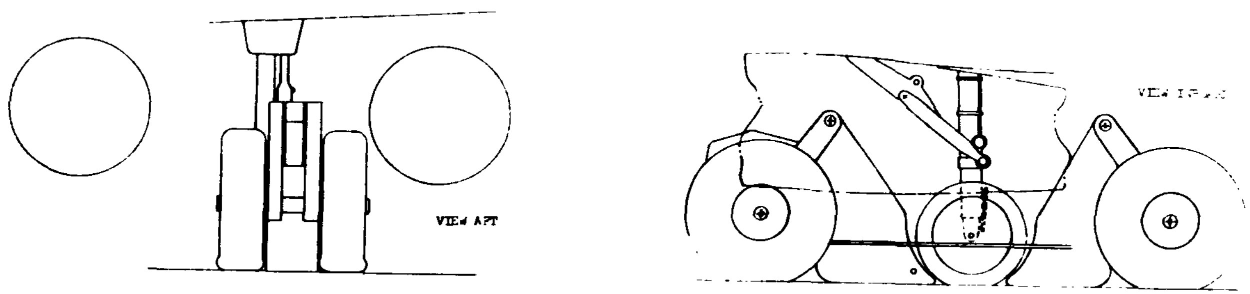


PLATE 32. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE A4D IN GROUND POSITION. (SCALE: 1 40)

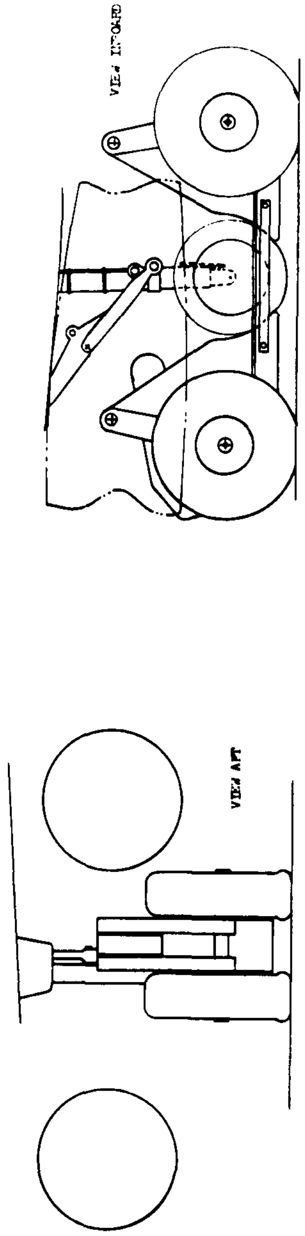


PLATE 33. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE AND IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

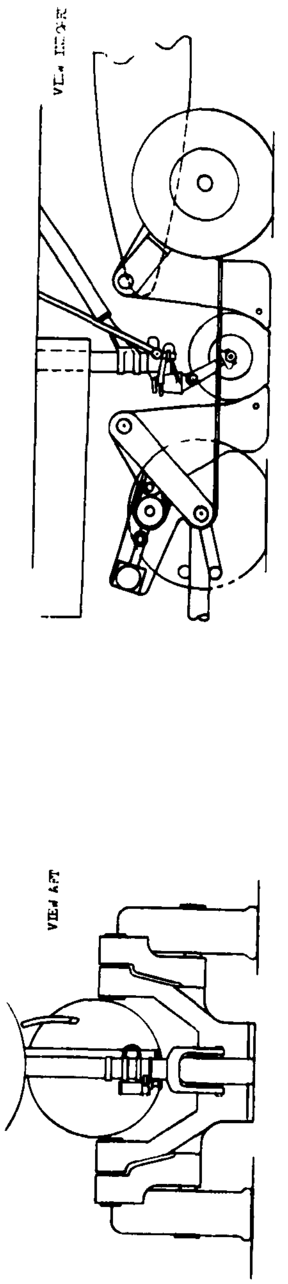


PLATE 34. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE AND IN GROUND POSITION. (SCALE: 1/40)

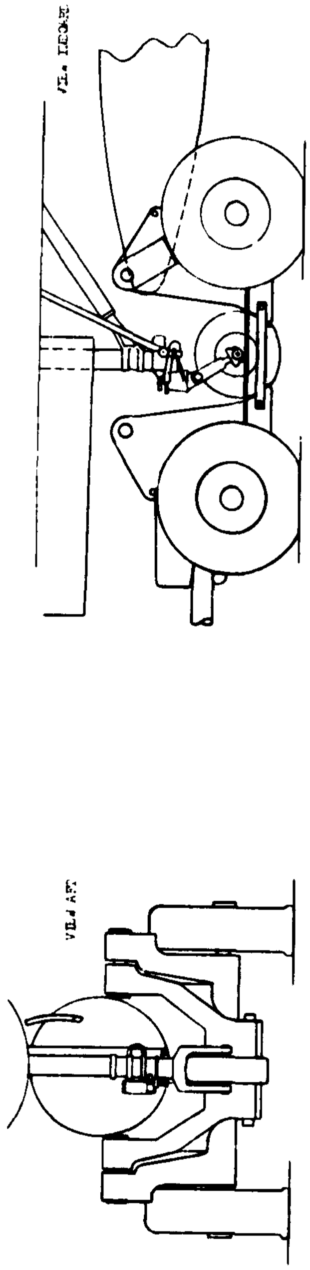


PLATE 35. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE A4D IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

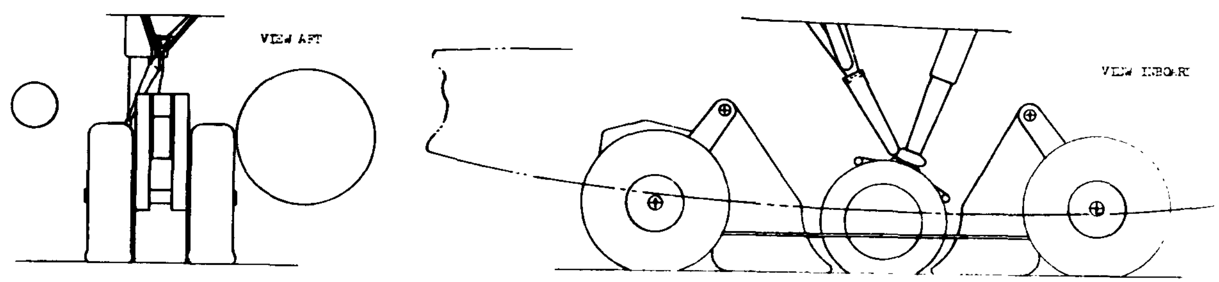


PLATE 30. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4C IN GROUND POSITION. (SCALE: 1:40)

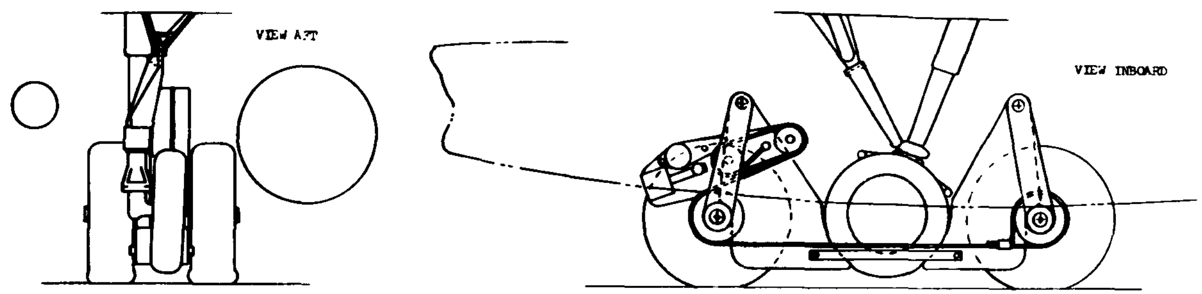


PLATE 37. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4D IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

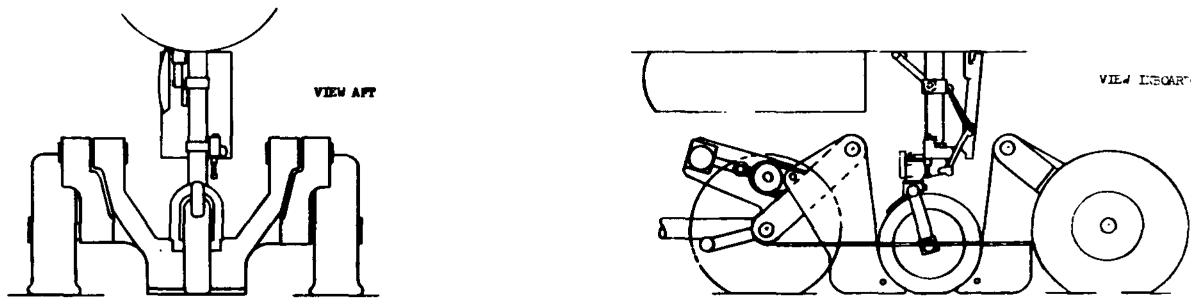


PLATE 38. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4D IN GROUND POSITION. (SCALE: 1/40)

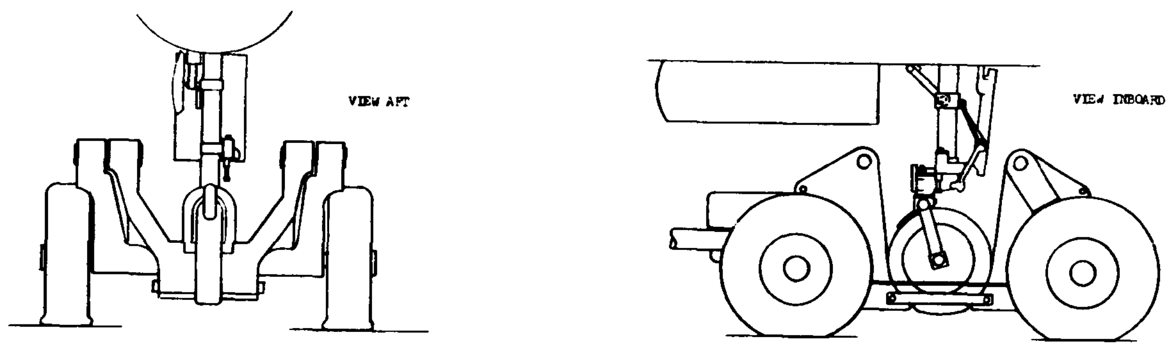


PLATE 39. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4D IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

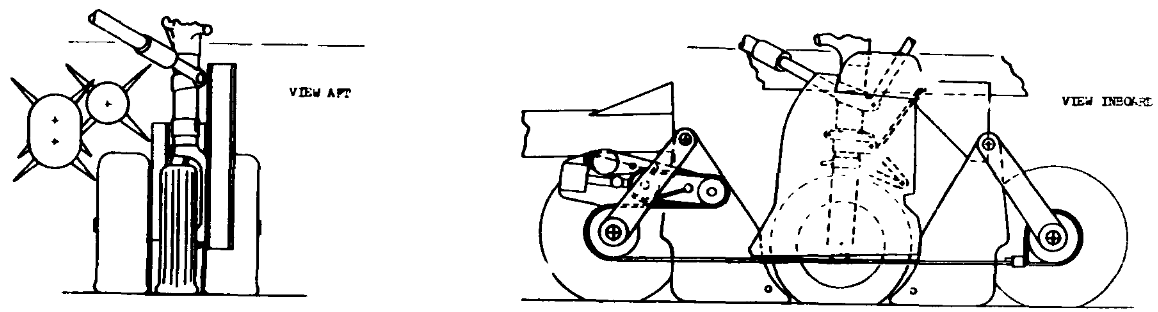


PLATE 40. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4H IN GROUND POSITION. (SCALE: 1/40)

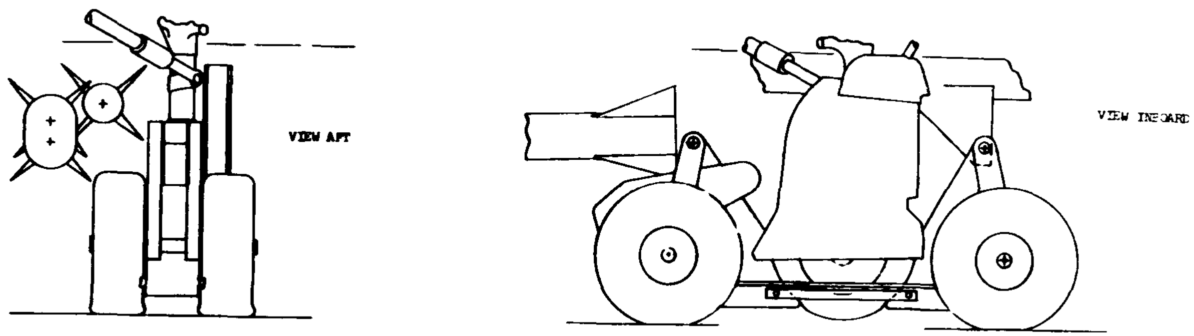


PLATE 41. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4E IN ELEVATED AND TOWING POSITION.
(SCALE: 1/40)

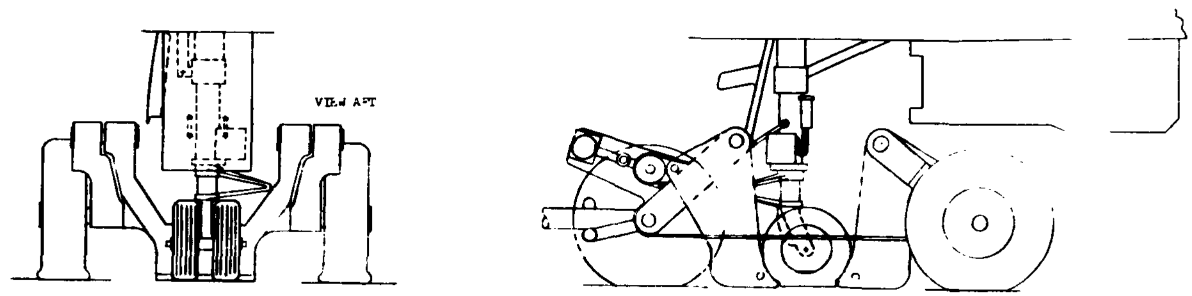


PLATE 42. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4H IN GROUND POSITION (SCALE: 1/40)

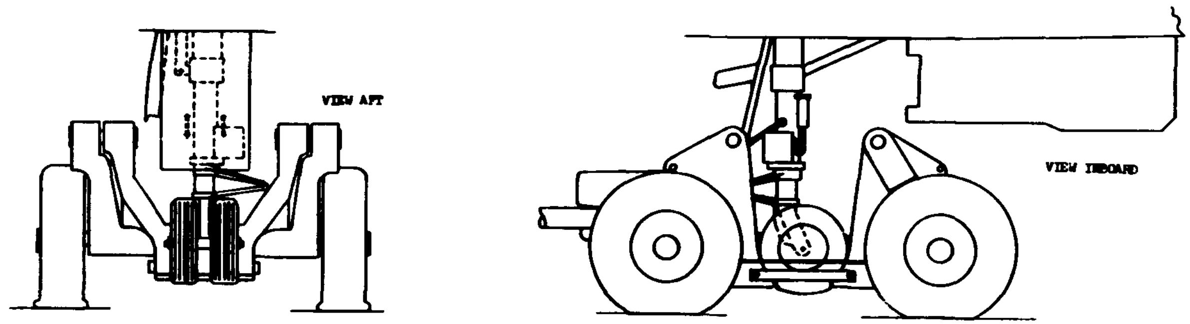


PLATE 43. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPE F4H IN ELEVATED AND TOWING POSITION.
(SCALE: 1/40)

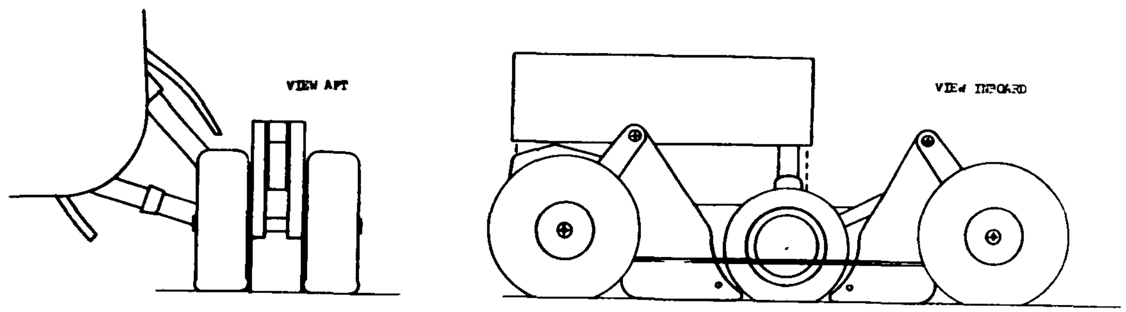


PLATE 44. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPES F8U-1 AND F8U-2 IN GROUND POSITION. (SCALE: 1/40)

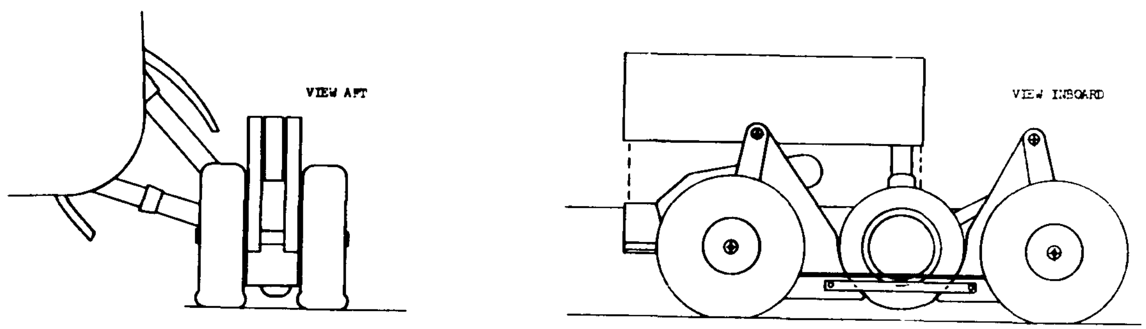


PLATE 45. MAIN GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPES F8U-1 AND F8U-2 IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

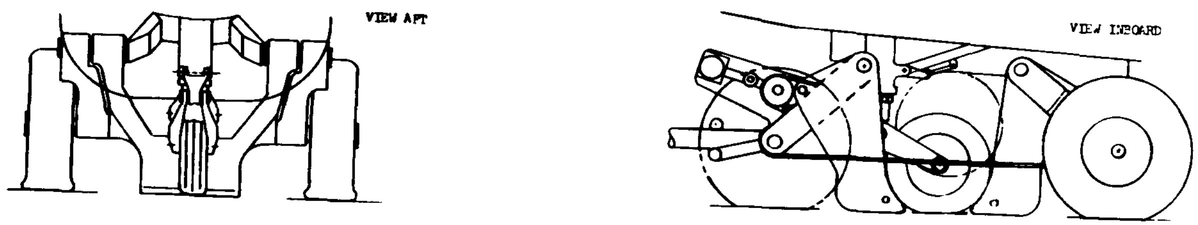


PLATE 46. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPES F8U-1 AND F8U-2 IN GROUND POSITION. (SCALE: 1/40)

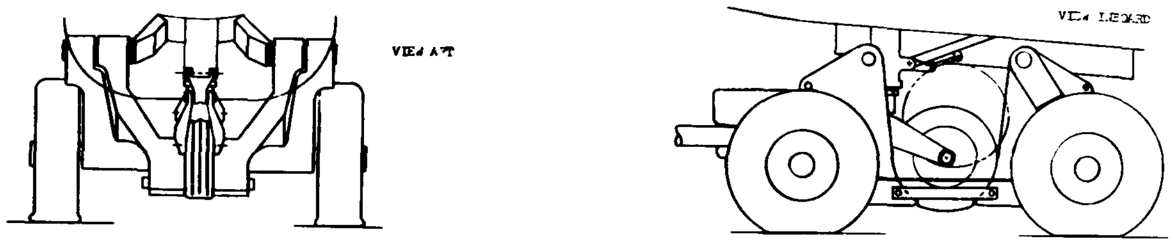


PLATE 47. NOSE GEAR FLOTATION DOLLY SHOWN WITH AIRCRAFT TYPES F8U-1 AND F8U-2 IN ELEVATED AND TOWING POSITION. (SCALE: 1/40)

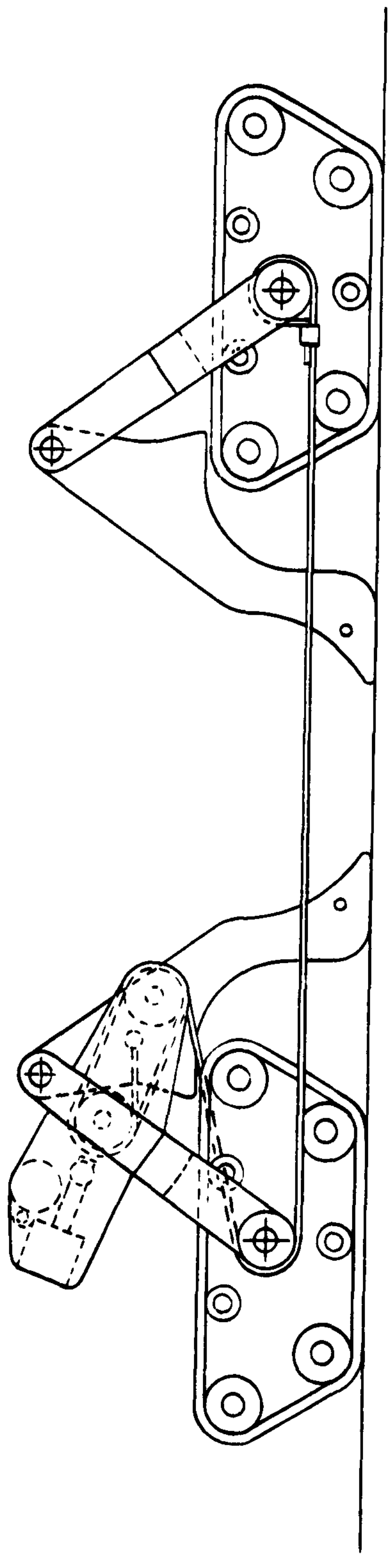
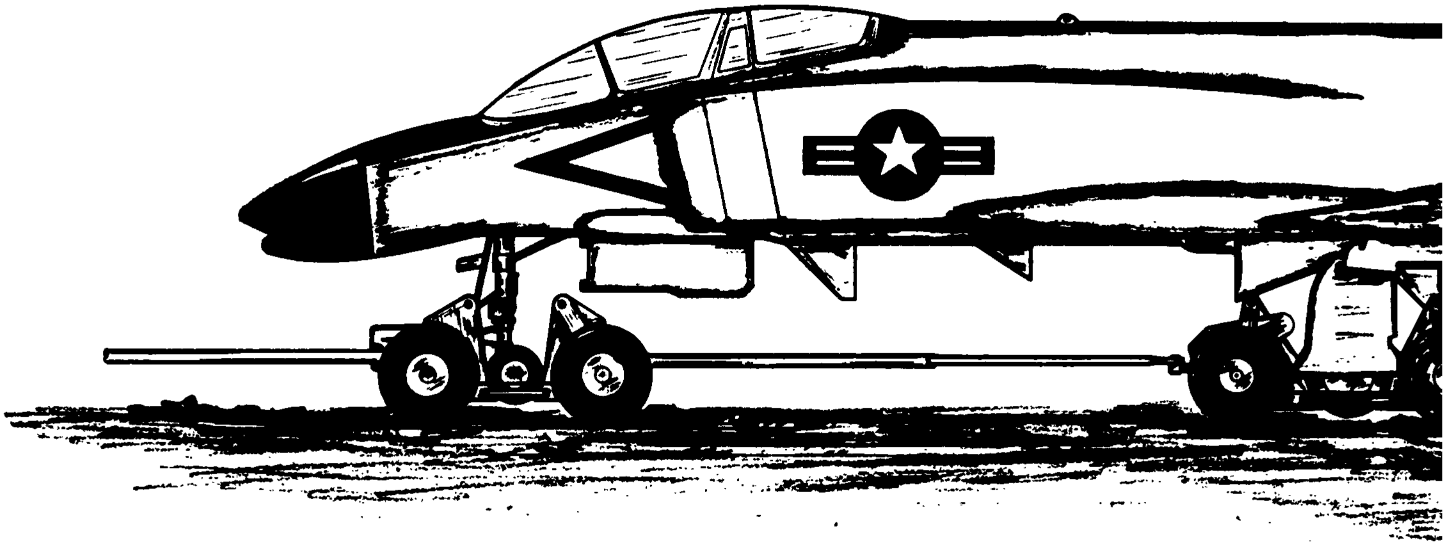


PLATE 48. ALTERNATE DOLLY SYSTEM UNIT MULTIPLE V-BELT TRACKS, FOR ADDED FLOTATION AND REDUCED TOWING FORCES.



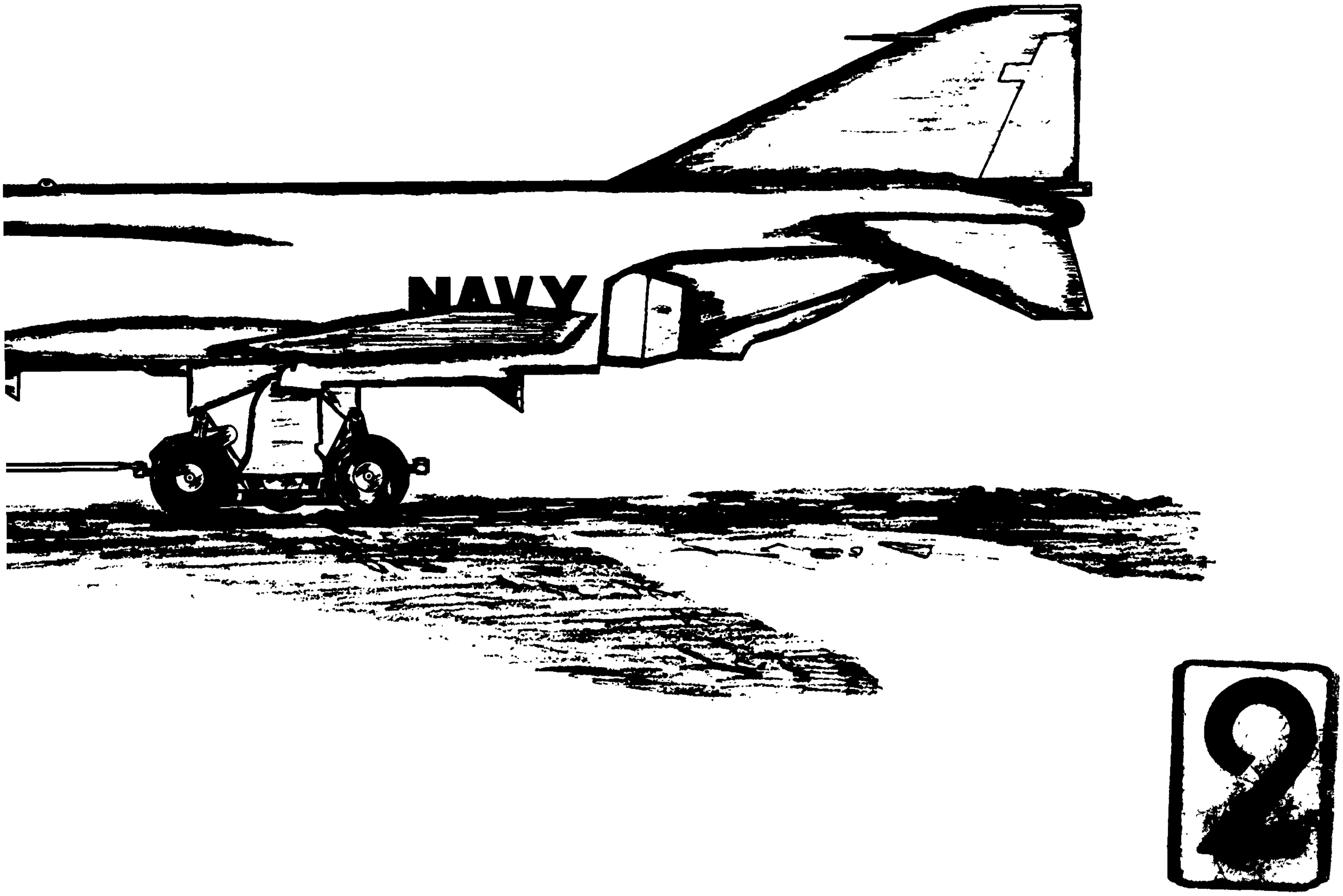
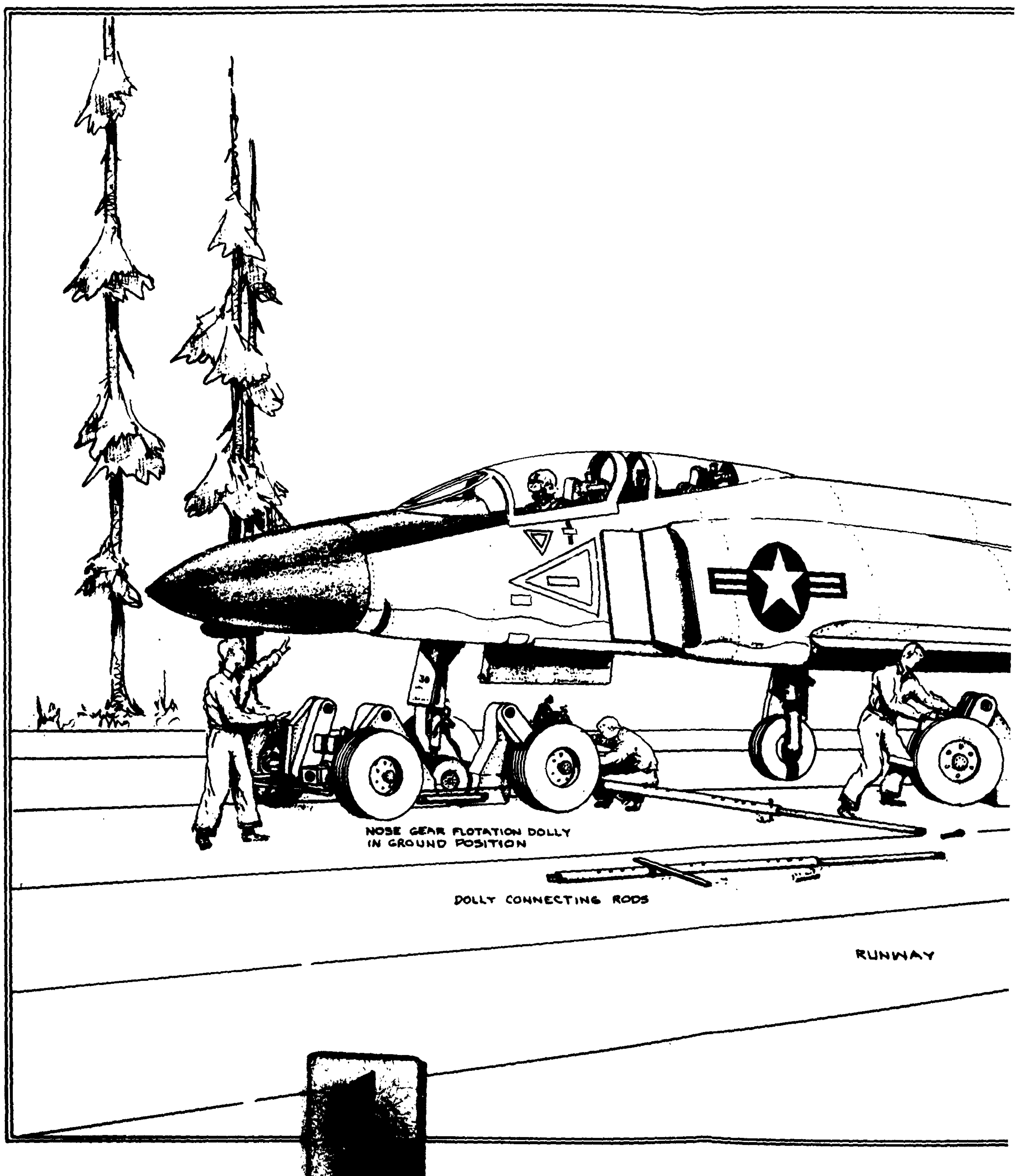


PLATE 49. SIDE ELEVATION OF AIRCRAFT F4H
SHOWN IN ELEVATED AND TOWING POSITION
(SCALE 1/40)


NOSE GEAR FLOTATION DOLLY
IN GROUND POSITION
DOLLY CONNECTING RODS
RUNWAY

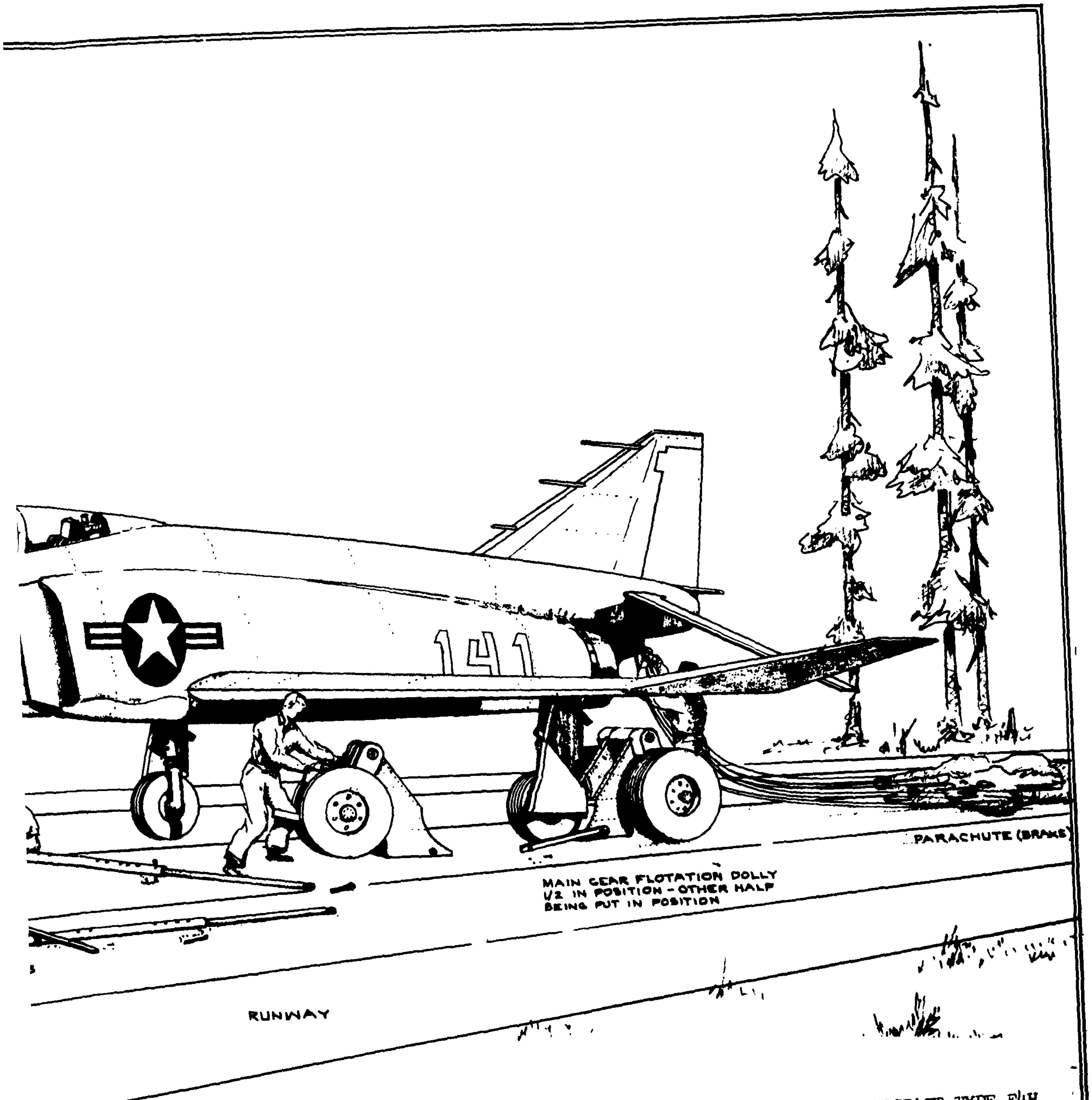
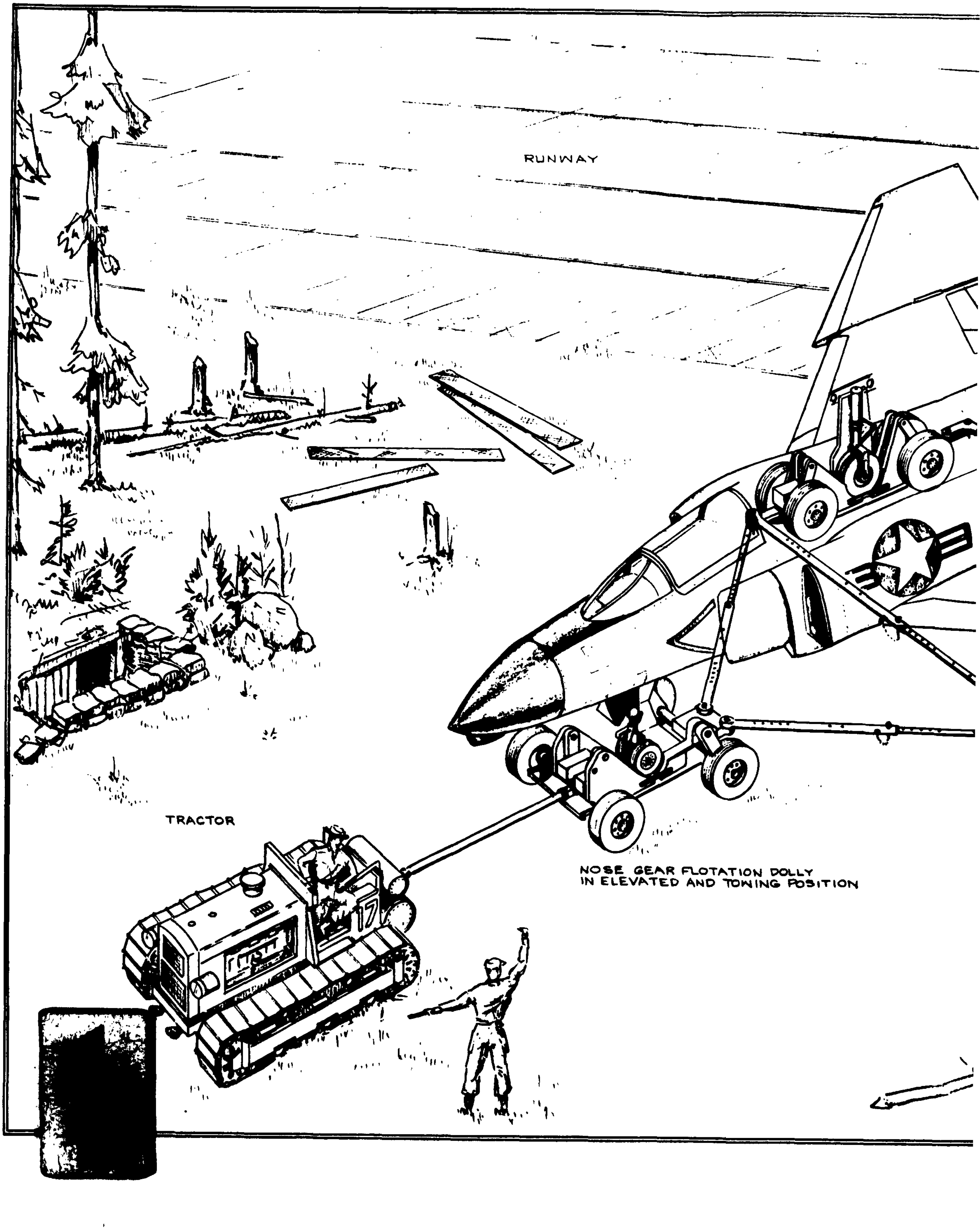


PLATE 50. PICTORIAL VIEW OF AIRCRAFT TYPE F4H WITH FLOTATION DOLLIES IN PROCESS OF INSTALLATION.


RUNWAY
TRACTOR
NOSE GEAR FLOTATION DOLLY
IN ELEVATED AND TOWING POSITION

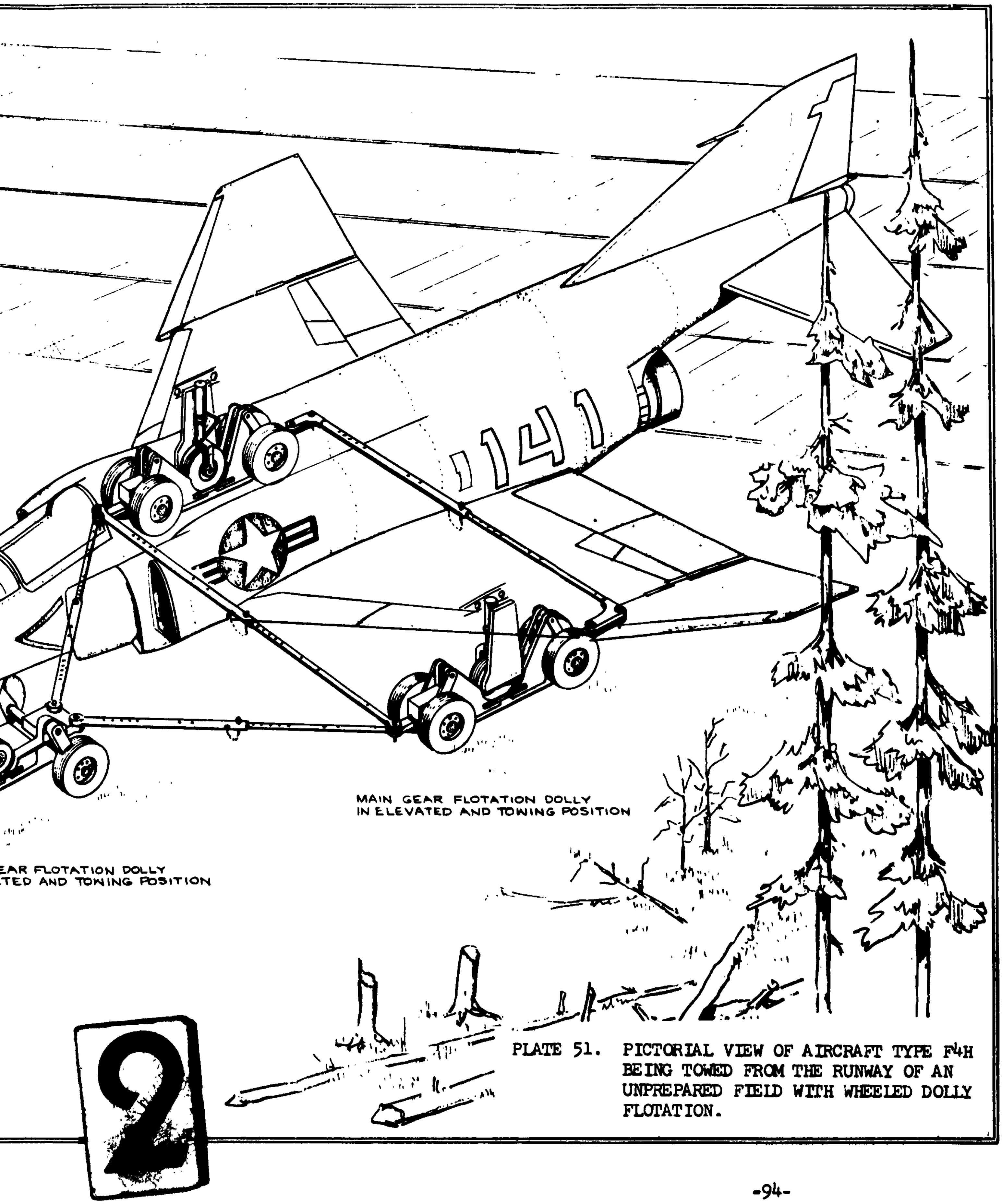


PLATE 51. PICTORIAL VIEW OF AIRCRAFT TYPE F4H BEING TOWED FROM THE RUNWAY OF AN UNPREPARED FIELD WITH WHEELED DOLLY FLOTATION.